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Impact of Eucalyptus Biodiesel and Nanoparticle Additives on Diesel Engine Performance

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ABSTRACT

This study delves into the potential of eucalyptus biodiesel as a future fuel alternative, focusing on its impact on key engine performance metrics: brake thermal efficiency (BTE) and brake-specific fuel consumption (BSFC). Eucalyptus biodiesel was produced through a controlled transesterification process, further incorporating oxide particles and nano-aluminum to investigate potential quality enhancements. Blends of varying biodiesel proportions (D95-B5, D90-B10, D85-B15) were systematically evaluated in a water-cooled, four-stroke, four-cylinder diesel engine across diverse operating conditions (1200, 1400, and 1600 rpm at 25%, 50%, and 75% load). Findings revealed a gradual decline in BTE and an increase in BSFC with increasing eucalyptus biodiesel content, indicating a decrease in overall fuel efficiency. To address this challenge, a further experiment explored the addition of nanoparticles (50 ppm, 75 ppm, and 100 ppm) to the D85-B15 blend. This strategic modification yielded a promising result: a significant improvement in both BTE and BSFC, highlighting the potential of nanoparticle additives to mitigate the efficiency drawbacks of eucalyptus biodiesel. Notably, this positive trend strengthened with increasing nanoparticle concentration and operating parameters.

1. INTRODUCTION

In recent decades, the globe has experienced significant scientific and economic progress, accompanied by continuous population growth. As a result, the need for transportation has also increased significantly. Consequently, scientists and engineers have researched methods to improve the performance and efficiency of internal combustion engines [1, 2]. These engines are a crucial aspect of our current industrial and technological age, as they directly influence many aspects of modern human life and its numerous demands [3, 4].

Biodiesel is a renewable raw material produced in large quantities through various processes. It is typically made via the esterification of animal fats, vegetable oils, and waste oils in the presence of a catalyst [5, 6]. When used as an engine fuel, the main advantage of biodiesel is that almost no modifications to the engine are required [7, 8].

It has almost the same engine performance regarding brake thermal efficiency (BTE), brake-specific fuel consumption (BSFC), and braking power [9, 10]. Nevertheless, researchers have found various negative consequences in tests with diesel-biodiesel fuel blends, such as low cloud and pour points, poor fuel injection atomization, low heating value, and overall high NOx emissions [11-13]. In recent years, researchers have explored the potential of nanoparticles as additives to enhance the performance of both diesel fuel and engines [14, 15]. By incorporating nanoparticles, such as cerium oxide or iron oxide, into diesel fuel formulations, combustion characteristics can be improved, leading to more efficient energy conversion and reduced emissions [16-18]. These nanoparticles act as catalysts, facilitating more complete fuel combustion and reducing the formation of harmful by-products. Additionally, they can enhance lubrication properties, potentially reducing wear and extending engine lifespan [19-21].

As a result, researchers have been experimenting with new techniques to increase engine performance by adding nanomaterials to fuel mixtures. Therefore, looking for alternative and improved diesel fuels is important. Khond et al. [22] explored nanofuel additives in compression engines using diesel, biodiesel, and water-emulsified fuels. They found that adding nanoparticles increased calorific value and cetane index while slightly raising density, flash point, and viscosity. Nanoparticles also reduced BSFC due to improved calorific value, catalytic oxidation, and complete combustion. Youssef et al. [23] tested diethyl ether (DEE), butanol (Bu), and zinc aluminum oxide ($ZnAl_2O_4$) nanoparticles as additives in a D70B30 diesel-biodiesel blend. Butanol increased brake power by 12.1% and reached 36.1% brake thermal efficiency at 75% load. DEE slightly reduced performance, while $ZnAl_2O_4$ improved brake power by 5% and cut fuel consumption by 3% with 100 ppm. Mofijur et al. [24] focused on cost-effective strategies for developing biodiesel fuel additives. Adding NP mixes (CeO_2 + Al_2O_3) improved engine performance, emissions, and combustion efficiency. TiO_2 nanoparticles reduced smoke by 32.98%, CO by 30%, and unburned hydrocarbons by 28.68%. NOx, CO, HC, and smoke emissions dropped to 60%, while brake power and efficiency increased by 12%. Venkatesan et al. [25] developed a fuel blend that combines aqueous zinc oxide nanofluid with diesel to enhance engine performance and combustion. Denser blends possess higher kinematic viscosity and flash points than diesel but offer a significantly greater heating value. Radhakrishnan et al. [26] studied the impact of alumina nanoparticles on cashew nut shell biodiesel's emissions and performance. Unlike BD100, alumina nanoparticles blend with gasoline without surfactants. BD100A exhibited 8.8% and 10.1% reductions in HC and CO emissions compared to BD100. Rangabashiam et al. [27] analyzed the combustion, performance, and emissions of Pongamia biodiesel in a single-cylinder, water-cooled, four-stroke CI engine. Adding TiO_2 nanoparticles to the biodiesel (PBD100) at 50 and 100 ppm ratios improved combustion compared to standard biodiesel. Shekofteh et al. [28] found that adding eucalyptus oil to a diesel blend improved brake thermal efficiency in direct injection engines at advanced injection timing. Tarabet et al. [29] showed that eucalyptus biodiesel, created by transesterifying eucalyptus oil, and its blends (75%, 50%, and 25%) significantly reduce CO, unburned hydrocarbon, and other emissions at high engine loads. However, higher biodiesel ratios increased NOx emissions. Anandavelu et al. [30] demonstrated that a B10 eucalyptus biodiesel blend reduced BSFC by up to 2.93% but had a slightly lower BTE than diesel. Ellappan et al. [31] noted that a 30% biodiesel and 70% eucalyptus oil blend in LHR engines reduced exhaust emissions by 3-4% but increased NOx emissions. Azad et al. [32] examined mustard oil-diesel blends (B5, B20, B30, and B40) and found that B20 and B30 had higher brake thermal efficiency but lower calorific value. Hoseinpour et al. [33] showed that mixing gasoline vapor with regular diesel reduced waste heat by up to 6.4%, increasing energy efficiency by 5% at medium load. Geng et al. [34] studied how soybean crude oil biodiesel affects a diesel engine's performance, exhaust emissions, and combustion characteristics. They compared diesel and biodiesel engines' design, emissions, and combustion characteristics. Buyukkaya et al. [35] studied how pure rapeseed oil and its 5%, 20%, and 70% blends compare to regular diesel fuel in terms of combustion, performance, and emissions. They found that pure rapeseed oil and the blends had shorter ignition delays than conventional diesel. The properties of rapeseed oil and its blends closely matched those of regular diesel. Devan et al. [24] studied the impact of antioxidant compounds on NOx emissions in a robust diesel engine using Annona biodiesel. Their experimental results indicate that adding an antioxidant reduces NOx emissions in diesel engines. Balaji et al. [36] examined the impact of an antioxidant additive (A-tocopherol acetate) on oxidative stability and NOx emissions in a direct injection diesel engine running on neem oil methyl ester. The antioxidant improved oxidation stability and lowered NOx emissions but increased HC, CO, smoke, and brake-related energy consumption. Lucas et al. [37] dosed calophyllurn iodophilic biodiesel with titanium oxide (TiO_2) nanoparticles (50 mg/L) and studied the performance of a water-cooled single-cylinder engine. Biodiesel combined with nanoparticles minimized CO emissions, particularly with the addition of cobalt oxide (Cu_3O_4). Sathish Kumar et al. [38] investigated a 20% eucalyptus oil blend (Eu20) with diesel using a common rail direct injection (CRDi) engine. The optimized setup achieved a brake thermal efficiency (BTE) of 16.766%, brake specific fuel consumption (BSFC) of 0.516 kg/kW-hr, and low emissions. However, Eu20 had lower BTE and higher fuel consumption than diesel. Adding zirconium oxide nanoparticles (50 and 100 ppm) to Eu20 improved efficiency and reduced fuel consumption. Kalaimurugan et al. [39] conducted experimental research on the performance, combustion, and emissions of a variable compression engine using copper oxide nanoparticles as additives in a diesel-biodiesel blend. Findings showed that adding CuO_2 nanoparticles improved combustion, enhanced performance, and reduced emissions. Prabu [40] evaluated a single-cylinder DI diesel engine's performance, combustion, and emissions with three fuel blends: B20, B20A30C30, and B100A30C30. They added alumina (Al_2O_3) and cerium oxide (CeO_2) nanoparticles (30 ppm each) using ultrasonication. The B20A30C30 blend improved brake thermal efficiency by 12% and cut NO emissions by 30%, CO by 60%, hydrocarbons by 44%, and smoke by 38% compared to B100.

This experimental investigation into combining nanoparticles into diesel fuel aims to explore novel approaches to improve engine efficiency and advance sustainable transportation solutions that align with global efforts to mitigate climate change and reduce dependence on finite fossil fuel reserves. By systematically testing different nanoparticle additives and evaluating their effects on combustion processes, the aim is to identify optimal formulations that offer tangible benefits in terms of improved fuel combustion and extended engine life. The performance of a variable four-cylinder four-stroke engine running on different fuel blends, namely diesel fuel with eucalyptus fuel in different proportions and diesel fuel with eucalyptus fuel with the addition of nano-aluminum oxide, has been investigated.

2. MATERIALS AND METHODS

This section presents a comprehensive description of the laboratory test devices, in addition to the computational aspect, where mathematical equations were used to find the value of braking power, brake thermal efficiency, and specific fuel consumption that affects the internal combustion engine's performance. Table 1 lists the specs of a Korean four-cylinder, four-stroke, water-cooled diesel engine utilized in this experiment.

Table 1. Engine specifications

Engine Manufacturer	Kia Bongo (Korea)
Type of Engine	J2 2701
Piston Displacement	2694 cm^3
Stroke	95 mm
Bore	95 mm
Nominal Output	80 HP at 4000 rpm
Maximum Torque	16.8 Nm. at 2400 rpm

The electric generator used in the experiment was a Chinese-made STC 24 kW model, operating at a frequency of 50 Hz. It generates a voltage of 220 volts and a current of 30 amperes per line across its three-phase system.

Electric loads of thermal heating wires were used to convert electrical energy into heat. The experimental engine featured nine heaters arranged in three groups connected to an electric line. An operating switch and voltage regulator controlled the current flow. Each heater had a 4,000-watt capacity.

Engine speed was measured electronically using a magnetic sensor connected to a speed-measuring device on the control panel. The sensor, placed close to the pilot wheel, detects its teeth and converts magnetic signals into electronic ones, which are displayed on the speed-measuring device, as seen in Figure 1.

Figure 1. Engine speed measuring device

During the experiment, diesel fuel obtained from a local gas station in Iraq served as the base. Seven distinct fuel types were investigated: three blends containing nanomaterials and biofuel, three with biofuel alone, and one with pure fuel for comparison.

The nanomaterials utilized were aluminum oxide, procured from the market. commercially available ultrasonic device, depicted in Figure 2(a), facilitated the homogenous mixing of biofuel, nanomaterials, and diesel fuel. The nanomaterial was precisely weighed using an electronic scale, as depicted in Figure 2(b). Table 2 outlines the various fuel mixtures and their corresponding volumetric ratios.

Biodiesel was made using eucalyptus oil obtained locally, with methanol serving as the solvent and potassium hydroxide as the catalyst.

(a) ultrasonic device (b) Balance weight

Figure 2. Ultrasonic device and electronic scale

Eucalyptus oil, sourced from local markets and available in containers of various capacities, has a consistent density of 913 kg/m³. Laboratory-grade methanol, with a purity of 99.9% and a 972 kg/m³ density, was also used, along with potassium hydroxide as the primary catalyst.

Figure 3(a) illustrates the materials employed in the production process. Initially, eucalyptus oil is heated to 80°C to eliminate any residual water content. Subsequently, the oil is transferred to a beaker and maintained at 60°C and 70°C, which serves as the reaction point. Meanwhile, the methoxide is prepared by dissolving a specific proportion of potassium hydroxide in methyl alcohol. For every 200 ml of oil, 50 ml of methyl alcohol is added, and 4 g of potassium hydroxide as the reaction catalyst. The methoxide is then combined with the oil, thoroughly mixing the materials. The reaction proceeds for over two hours, resulting in a product where biofuel accumulates at the top of the beaker while glycerin settles at the bottom, as depicted in Figure 3(b).

Table 2. Fuel mixtures and their volumetric ratios

No.	Mixture	Mixture Symbol	Volumetric Proportions of Components of the Mixture
1	Diesel	D100%	Diesel 100%
2	Diesel + biodiesel	D95% + B5%	95% Diesel 5% biodiesel(v/v)
3	Diesel + biodiesel	D90% + B10%	90% Diesel 10% biodiesel(v/v)
4	Diesel + biodiesel	D85% + B15%	85% Diesel 15% biodiesel(v/v)
5	Diesel + biodiesel + nanoparticles	D85% + B15% + 50 ppm	85% Diesel 15% biodiesel(v/v) + 50 ppm nanoparticles(w/w)
6	Diesel + biodiesel + nanoparticles	D85% + B15% + 75 ppm	85% Diesel 15% biodiesel(v/v) + 75 ppm nanoparticles(w/w)
7	Diesel + biodiesel + nanoparticles	D85% + B15% + 100 ppm	85% Diesel 15% biodiesel(v/v) + 100 ppm nanoparticles(w/w)

(a) Materials used in production (b) The product of a chemical reaction

Figure 3. Method of production of biodiesel by esterification

This experimental setup assessed braking power using the generator head (an electric generator). The electric power measuring device, integrated into the control panel, precisely records each line's electric power, voltage, and current (PHASE). The relevant equation governing this measurement is as follows [41, 42]:

$$BP = \frac{P_{Elec}}{\eta_{Gen}} \tag{1}$$

where, BP is the brake power (kW); P_{Elec} is the total electrical power (kW); and η_{Gen} is the efficiency of electric generator (%). The resulting total electrical power can be calculated using the following equation [43]:

$$P_{Elec} = P_{L1} + P_{L2} + P_{L3} \tag{2}$$

where, P_{L1} is the electrical power of the first line, P_{L2} is the electrical power of the second line, and P_{L1} is the electrical power of the third line. Moreover, the electrical power of each line can be calculated using the following equation [44]:

$$P_{Elec} = \mathrm{V} * \mathrm{I} * \mathrm{PF} \tag{3}$$

where, V is the voltage (potential difference) (V), I is the current (A), and PF is the power factor (%). The power factor changes continuously depending on the amount of current and the amount of voltage.

Brake thermal efficiency (BTE) is the extent of the engine's efficiency in converting the energy resulting from fuel combustion into mechanical energy, and it is the result of dividing each of the braking power values by the calorific value of the fuel resulting from its combustion. The efficiency is calculated from the following equation [41, 42]:

$$\eta_{bth} = \frac{\mathrm{BP}}{\dot{m}_f * \mathrm{LCV}} \quad (4)$$

where, η_{bth} is the braking thermal efficiency (%), $\dot{m}_f$ is the average fuel consumption (kg/s), and CV is the calorific value (kJ/kg). A graduated glass tube was placed on the control panel. It was filled with a small pump connected to the fuel tank and equipped with a valve to supply the engine with fuel during the measurement process, as the consumption is calculated by calculating a specific amount of fuel, which is 50 ml for a specific time period of seconds using a stopwatch Figure 4 shows the consumption measurement plan. It is done according to the equation [41, 42]:

$$\dot{m}_f = \mathrm{sg}_f \times \mathrm{v} \times 0.001 / \mathrm{t} \quad (5)$$

where, $\dot{m}_f$ is the fuel consumption (kg/s), sg_f is the specific weight of fuel (kg/cm^3), V is the volume of spent fuel in cm^3, and t is the time spent. The brake-specific fuel consumption (BSFC) is the result of dividing the amount of fuel consumption by the braking power [41, 42]:

$$\mathrm{BSFC} = \frac{\dot{m}_f}{\mathrm{BP}} \quad (6)$$

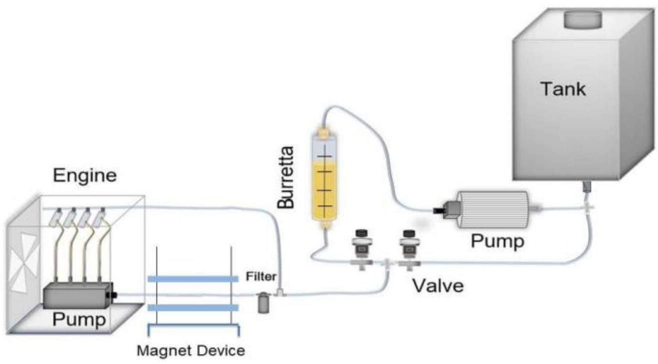

Figure 4. Fuel consumption measurement

It is necessary to perform an uncertainty analysis. of the tests performed as it is important to provide the highest level of confidence in all results and can be obtained through the repetition of the results and accuracy in taking them where the variable values of the performance factors were used to calculate the uncertainty using the relative standard error percentage, ∅, as shown in equation [45]:

$$\emptyset\% = \left(\frac{S}{Y}\right) \times 100 \quad (7)$$

where, S is the standard error, and Y is the average of the data collected. Standard error calculated according to equation [45]:

$$s = \frac{\propto}{\sqrt{k}} \quad (8)$$

where, α is the standard deviation, and k are the repeatable readings of the performance characteristics. The general empirical uncertainty, $\propto_n$, was calculated using equation [45]:

$$\propto_n = \sqrt{\propto_1{}^2 + \propto_1{}^2 + \cdots + \propto_i{}^2} \quad (9)$$

where, $\propto_n$ is the total uncertainty, and $\propto_1$, $\propto_2$ and $\propto_i$ are the uncertainties of the individual parameters.

The uncertainties of the measured parameters are detailed in Table 3.

Table 3. Uncertainties of the measured parameters

Parameter	Max. Value	Uncertainty
Speed (rpm)	1600	±0.09
BSFC (kg/kw.hr)	0.324	±1.3
BTE (%)	19.7	±0.88

3. RESULTS AND DISCUSSIONS

This section examines the practical testing of a four-stroke, four-cylinder diesel engine fueled by various diesel-biofuel blends. Seven mixtures were created by combining standard diesel with six different biofuel types (eucalyptus) at varying volumetric proportions. The engine was operated at different speeds and loads, with a focus on its thermal performance, a key aspect of internal combustion studies. Key performance parameters like braking efficiency and brake-specific fuel consumption are presented and analyzed through graphs. The discussion evaluates the engine's behavior under these diverse fuel combinations, providing insights into the performance implications of blending diesel with biofuels and incorporating nano aluminum oxide.

Figures 5-7 reveal how engine load and speed affect the relationship between brake thermal efficiency (BTE) and the percentage of eucalyptus biodiesel mixed with diesel fuel. The tests used three engine speeds (1200, 1400, and 1600 rpm) and three biodiesel ratios (5%, 10%, and 15%).

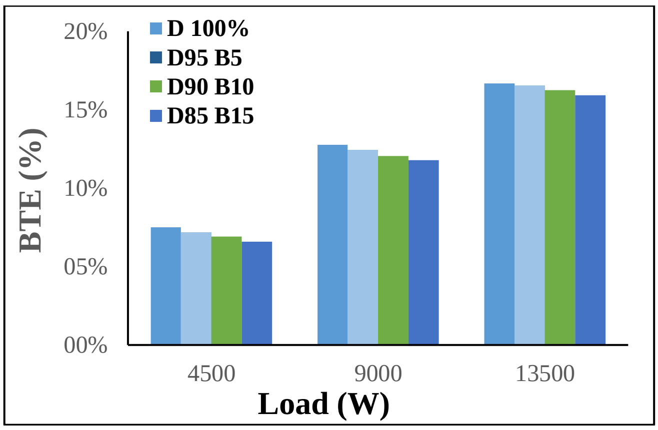

Figure 5. BTE vs. engine load at 1200 rpm

These figures indicate that the engine doesn't operate at its peak efficiency at low loads, resulting in low BTE for both pure diesel and biodiesel blends. Adding eucalyptus biodiesel may cause lower BTE than pure diesel due to biodiesel's lower oxygen content, reducing combustion efficiency. Higher BTE results from the engine operating more efficiently at increased loads. Biodiesel mixes tend to burn more completely and stably, potentially yielding higher BTE. However, since biodiesel contains less energy than diesel, too high a biodiesel ratio can reduce BTE at higher loads. As expected, BTE increased with both higher load and engine speed. Interestingly, the 5% biodiesel blend exhibited the closest performance to pure diesel, followed by 10% and 15% blends. Similar trends were observed in a previous study [46]. The engine burns more fuel per cycle at higher loads, optimizing the air-fuel mixture and improving combustion efficiency. Higher loads also stabilize combustion due to a consistent, robust mixture, enhancing energy extraction and conversion efficiency.

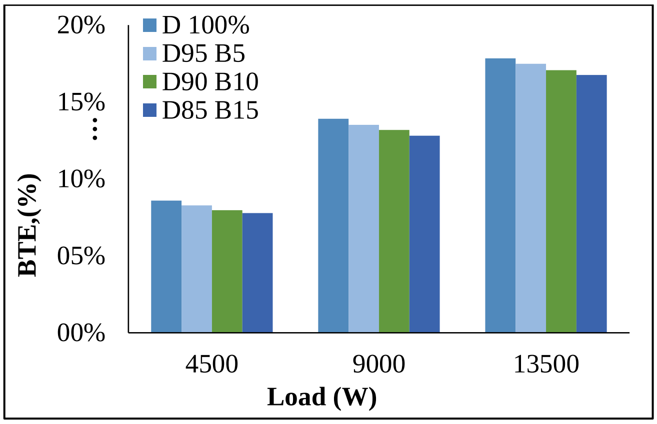

Figure 6. BTE vs. engine load at 1400 rpm

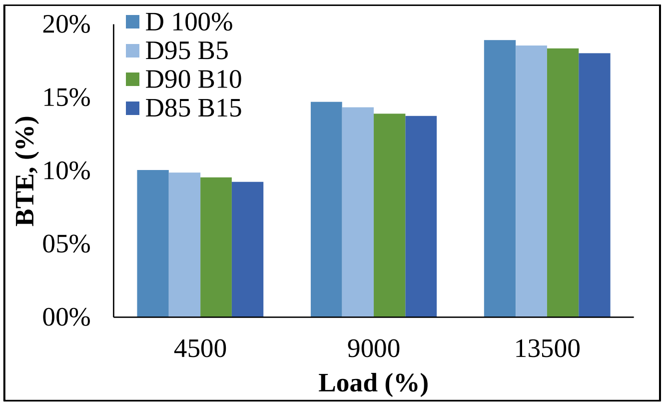

Figure 7. BTE vs. engine load at 1600 rpm

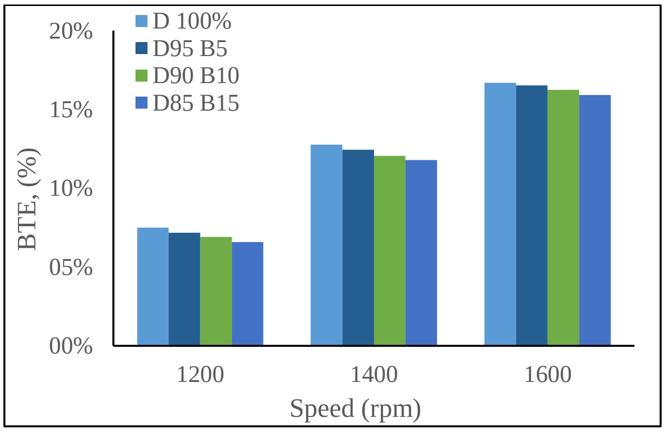

Figure 8. BTE vs. speed at 13500 W load

Figure 8 shows how engine speed and biofuel content affect brake thermal efficiency (BTE). At a constant load of 13,500 W, BTE generally increases with speed but decreases with higher biofuel ratios. At higher speeds, combustion is faster and more efficient, allowing more complete fuel energy conversion into practical work. The combustion chamber has less time to lose heat between power strokes, reducing wasted energy. Engines are optimized to operate efficiently within a specific speed range, enabling better fuel energy conversion at higher speeds.

Compared to pure diesel, the D95-B5 blend (5% biofuel) had a 1% lower BTE at 1200 rpm, rising to 3% and 4% for D90-B10 (10% biofuel) and D85-B15 (15% biofuel), respectively. Similar trends were observed at higher speeds: 1.7%, 4%, and 5% for 1400 rpm and 1.58%, 3.7%, and 4.8% for 1600 rpm. All biofuel blends had lower BTE than pure diesel. This is likely due to their lower calorific value compared to diesel fuel.

Figures 9-11 depict the interplay between engine load, speed, and brake-specific fuel consumption (BSFC) for diesel blends containing varying eucalyptus biodiesel ratios. At low loads, BSFC is higher for blends with substantial eucalyptus biodiesel content due to less efficient engine operation and biodiesel's lower energy density. Incomplete combustion and lower thermal efficiency further increase BSFC. As engine load rises, BSFC decreases for all blends due to improved efficiency. Biodiesel blends offer more consistent combustion with higher oxygen content, enhancing BSFC. Additionally, a positive correlation exists between engine speed and BSFC, with the magnitude of the increase being most pronounced in blends with higher biodiesel content. Notably, although higher loads generally lead to improved fuel efficiency (lower BSFC), this positive trend diminishes with increasing biodiesel content, following the order D95-B5 > D90-B10 > D85-B15. This divergence arises from the combined calorific values of biodiesel and diesel relative to pure diesel. These observations align with the findings reported in the study of Verma et al. [46].

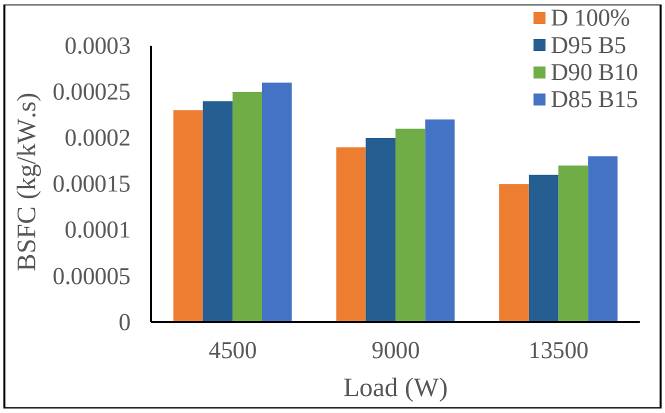

Figure 9. BSFC vs. engine load at 1200 rpm

Figure 12 demonstrates a direct correlation between brake-specific fuel consumption (BSFC) and both engine speed and the biofuel content of the fuel mixture at a constant load of 13,500 W. The findings show that the engine typically operates less efficiently at low speeds, leading to higher brake-specific fuel consumption (BSFC) for both pure diesel and eucalyptus biodiesel blends. Eucalyptus biodiesel mixes show increased BSFC compared to pure diesel due to potential challenges with combustion stability and lower energy content. BSFC decreases for diesel-eucalyptus biodiesel mixes at moderate speeds because of improved combustion efficiency. The engine runs within its optimal efficiency range, improving fuel consumption, particularly for blends with moderate biodiesel levels.

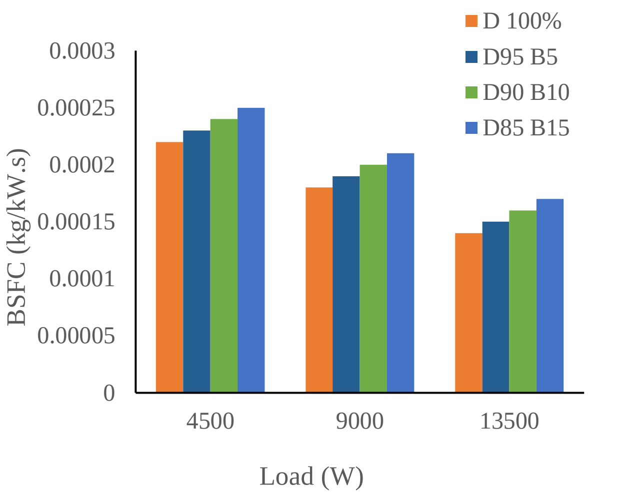

Figure 10. BSFC vs. engine load at 1400 rpm

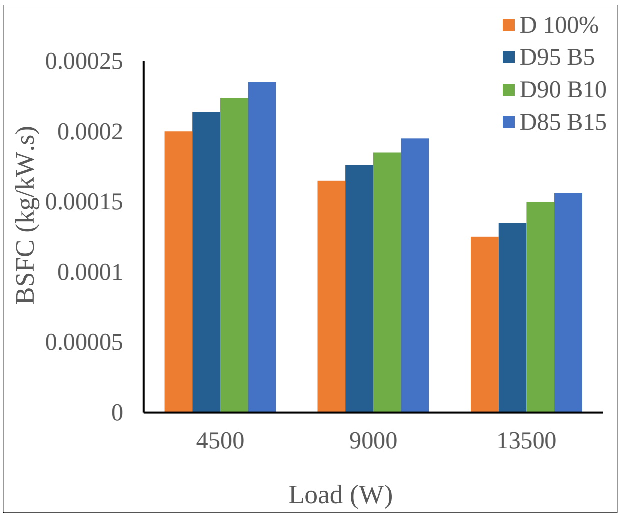

Figure 11. BSFC vs. engine load at 1600 rpm

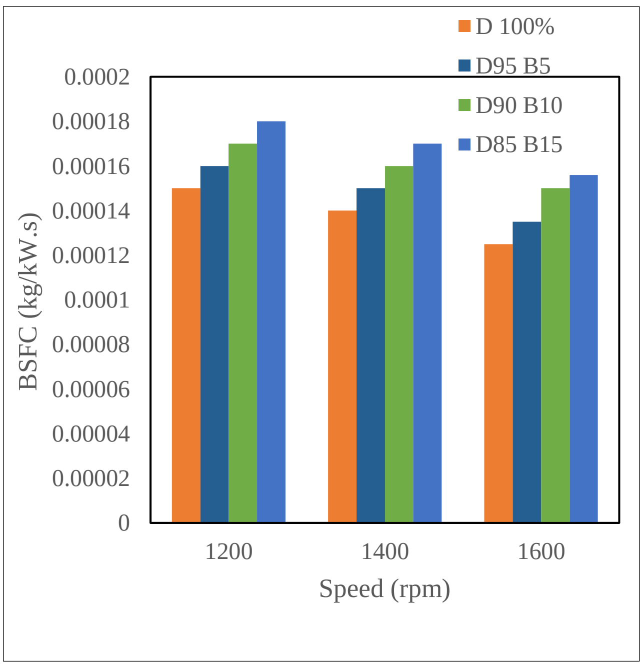

Figure 12. BSFC vs. speed at 13500 W load

The results show that the D85-B15 blend exhibits the highest BSFC values across all speeds. Compared to pure diesel, the BSFC differences for D95-B5, D90-B10, and D85-B15 at 1200 rpm were 6%, 13.3%, and 20%, respectively. These differences widened at higher speeds, reaching 8%, 20%, and 25% at 1600 rpm. This observed increase in BSFC can be primarily attributed to the lower calorific value of biodiesel than diesel.

This study also investigated the synergy between biodiesel incorporation and nanoparticle additives in improving engine performance. Among various diesel-biodiesel blends, D85-B15 (85% diesel, 15% biodiesel) demonstrated optimal characteristics, prompting further analysis with nano aluminum oxide at 50 ppm, 75 ppm, and 100 ppm concentrations.

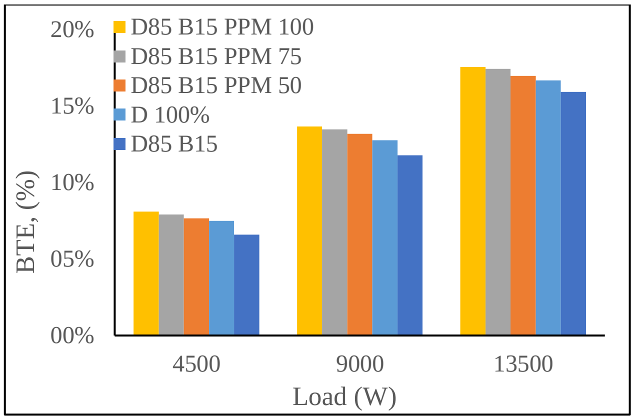

Figure 13. Effect of adding aluminum oxide particles to a mixture of diesel and biofuel at different loads at a speed of 1200 rpm

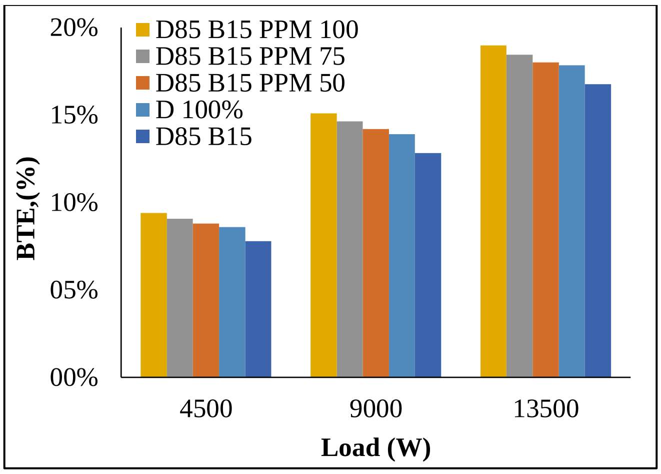

Figure 14. Effect of adding aluminum oxide particles to a mixture of diesel and biofuel at different loads at a speed of 1400 rpm

Figures 13-15 reveal the significant impact of these nanoparticles on the Brake Thermal Efficiency (BTE) of the D85-B15 blend across diverse load and speed conditions (1200, 1400, and 1600 rpm). The results reveal that the D85-B15 blend with varying levels of nano aluminum oxide usually achieves higher brake thermal efficiency (BTE) than pure diesel. This can be attributed to Al_2O_3's catalytic properties and the extra oxygen provided by biodiesel. As a result, combustion efficiency improves, leading to increased energy conversion across different load and speed conditions. BTE is lower in pure diesel due to the lack of oxygen and the catalytic benefits of biodiesel and nanoparticles. These observations align with prior research on the beneficial effects of nanoparticle additives in biofuel blends. These observations align with the findings reported in the study of Chen et al. [47].

Adding Al_2O_3 at a concentration of 50 ppm significantly enhances brake thermal efficiency (BTE) across all engine speeds. The improved combustion stability due to the catalytic properties of the nanoparticles is especially apparent at higher loads. At 75 ppm, Al_2O_3 significantly increases BTE, as the nanoparticles optimize the air-to-fuel ratio and promote more complete combustion, particularly noticeable at medium speeds (1400 rpm) and higher load conditions. When the concentration reaches 100 ppm, the catalytic effect of Al_2O_3 has the most substantial impact on BTE, especially at high loads. The nanoparticles facilitate complete combustion, improving energy conversion and maximizing BTE.

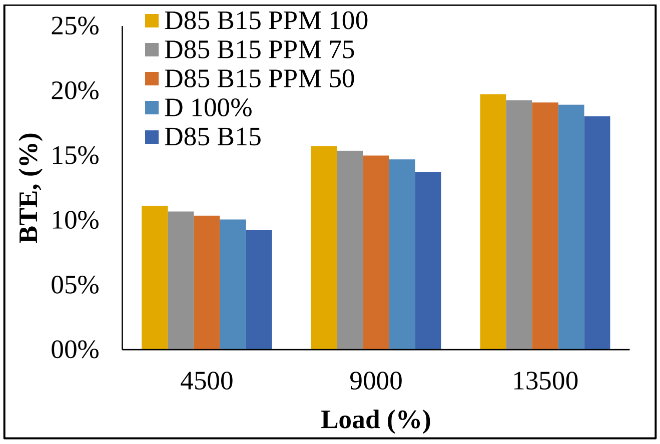

Figure 15. Effect of adding aluminum oxide particles to a mixture of diesel and biofuel at different loads at a speed of 1600 rpm

The experimental results investigated the effects of incorporating nano aluminum oxide additives on the brake thermal efficiency (BTE) of a D85-B15 biodiesel blend (85% diesel, 15% biodiesel). Figure 16 depicts the correlation between BTE and engine speed at a constant load of 13,500 W for varying nanoparticle concentrations (50 ppm, 75 ppm, and 100 ppm).

Across all tested blends, a consistent increment in BTE was observed with increasing engine speed. However, D85-B15 biodiesel outperformed pure diesel, particularly at higher nanoparticle concentrations. Table 4 summarizes the BTE differences between the nanoparticle-enhanced blends and pure diesel at different speeds:

Table 4. Variations in BTE between pure diesel and blends boosted with nanoparticles at different speeds

Engine Speed (rpm)	D85B15PPM50 BTE Improvement	D85B15PPM75 BTE Improvement	D85B15PPM100 BTE Improvement
1200	1.70%	4.00%	5.00%
1400	1.10%	4.93%	6.00%
1600	0.90%	2.10%	4.20%

This significant BTE enhancement is attributed to the effective dispersion of nanoparticles within the biodiesel blend. By potentially mitigating issues like clogging and facilitating improved fuel atomization, these nanoparticles contribute to superior combustion efficiency. Their highly reactive surface area likely acts as a catalyst, encouraging more efficient chemical reactions during combustion, resulting in better fuel utilization and reduced consumption.

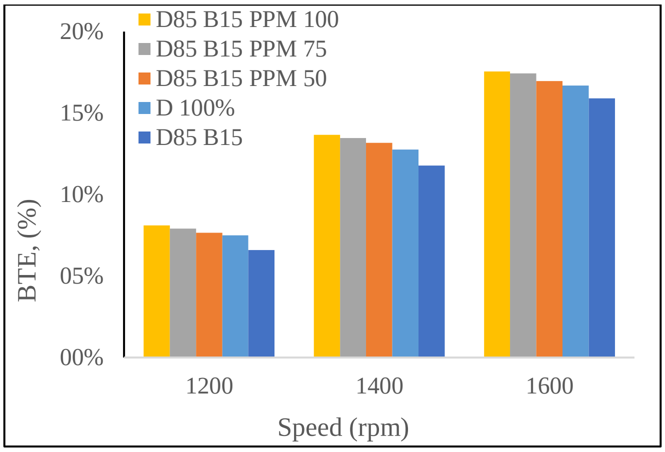

Figure 16. BTE vs. speed at 13500 W load

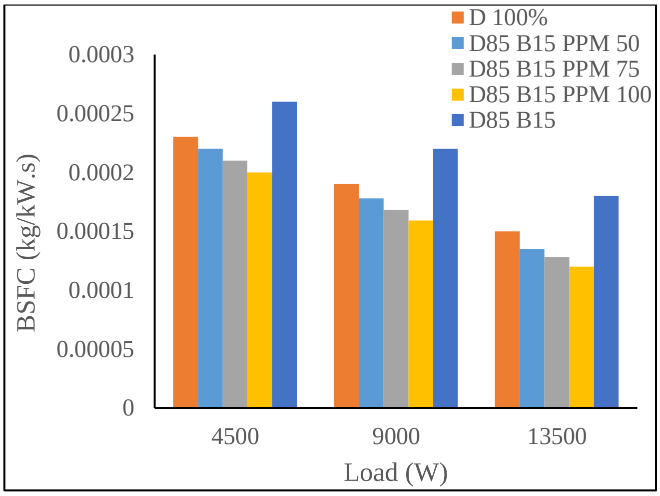

Figure 17. Difference in BSFC at different nano dosages when compared to plain diesel and a 15% biodiesel mix at 1200 rpm

Figures 17-19 delve into the impact of different nanoparticle doses on Brake-Specific Fuel Consumption (BSFC) in a blend of 15% biodiesel and 85% diesel (D85-B15) at 1200 rpm. BSFC represents the fuel used per unit of power and time, often higher for biodiesel due to its lower calorific value than diesel.

At 50 ppm, nano Al_2O_3 leads to a moderate reduction in BSFC across various loads and speeds, particularly at higher loads (13,500 W), as nanoparticles stabilize the air-fuel mixture to enhance combustion efficiency. At 75 ppm, Al_2O_3 nanoparticles have a stronger effect, significantly reducing BSFC at all load levels due to their catalytic properties, which promote complete combustion and efficient fuel conversion. At 100 ppm, nano Al_2O_3 lowers BSFC, especially at high loads (13,500 W) and medium speeds (1400 rpm), by optimizing combustion timing and completeness, greatly reducing fuel consumption.

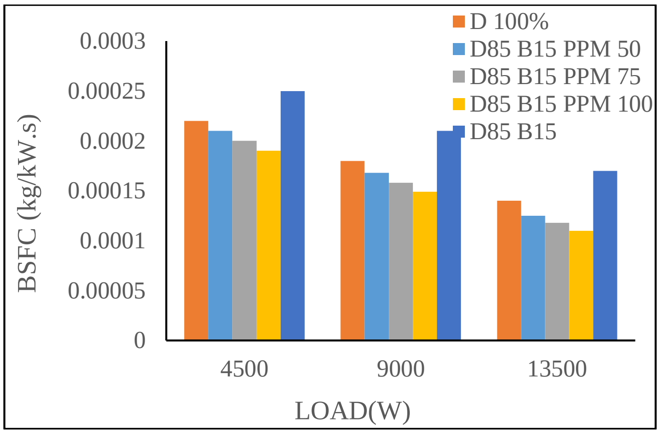

Figure 18. Difference in BSFC at different nano dosages when compared to plain diesel and a 15% biodiesel mix at 1400 rpm

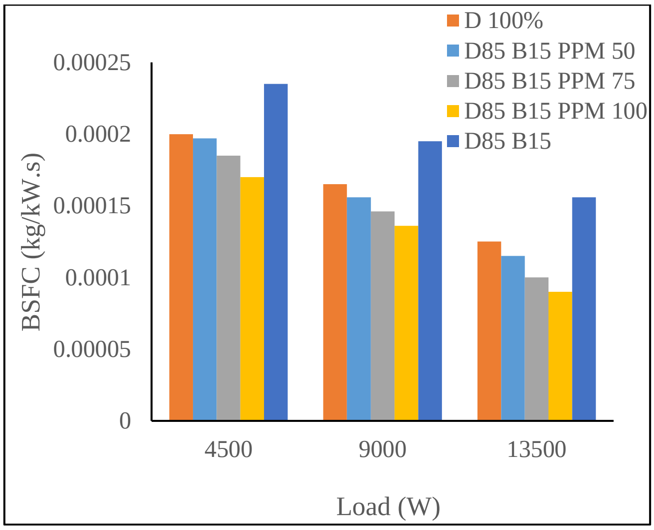

Figure 19. Difference in BSFC at different nano dosages when compared to plain diesel and a 15% biodiesel mix at 1600 rpm

4. CONCLUSIONS

The study explored the effects of eucalyptus biodiesel and nano aluminum oxide additives on the performance of diesel engines, focusing on brake thermal efficiency (BTE) and brake-specific fuel consumption (BSFC). The results showed that increasing the proportion of eucalyptus biodiesel in the blend reduced efficiency compared to pure diesel due to the lower energy content of biodiesel. Despite this, the D85-B15 blend (85% diesel, 15% biodiesel) remained a promising alternative with manageable reductions in efficiency, highlighting its potential as a renewable fuel source.

The addition of nano aluminum oxide at concentrations of 50 ppm, 75 ppm, and 100 ppm significantly improved both BTE and BSFC across all load and speed conditions. The 100 ppm concentration produced the most substantial improvements, optimizing combustion efficiency and reducing fuel consumption. These enhancements are attributed to the catalytic properties of the nanoparticles, which stabilize combustion and promote more complete fuel burning.

The study also examined the engine performance across varying loads (4500 W, 9000 W, and 13,500 W) and speed conditions (1200, 1400, and 1600 rpm). The results revealed that the nano-enhanced D85-B15 blend consistently achieved higher efficiency than pure diesel, maintaining balanced performance under diverse operating conditions. This consistency underlines the potential of nanoparticles to enhance the efficiency of biodiesel blends.

In summary, incorporating nano-aluminum oxide into combinations of eucalyptus biodiesel successfully alleviates the efficacy issues frequently linked to biodiesel. This amalgamation establishes a foundation for enhanced diesel engine efficiency and sustainability, thereby showcasing the potential for biodiesel alternatives to be more widely adopted in the future.

Future research could refine nanoparticle concentrations and explore different additives to enhance engine efficiency. Comparative studies can assess the impact of biodiesel blends on emissions while maintaining performance.

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NOMENCLATURE

CuO	Copper oxide
D85 B15	85% diesel, 15% biodiesel
D85 B15 PPM 100	85% diesel, 15% biodiesel with 100 ppm CuO nanoparticles
D85 B15 PPM 50	85% diesel, 15% biodiesel with 50 ppm CuO nanoparticles
D85 B15 PPM 75	85% diesel, 15% biodiesel with 75 ppm CuO nanoparticles
D90 B10	90% diesel, 10% biodiesel