International Journal of Design & Nature and Ecodynamics
Vol. 19, No. 3, June, 2024, pp. 907-916
Journal homepage: http://iieta.org/journals/ijdne

Enhancing Diesel Engine Performance with Different Concentrations of Copper Oxide Nanoparticles in Biodiesel Blends

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https://doi.org/10.18280/ijdne.190320

Received: 10 March 2024
Revised: 11 May 2024
Accepted: 20 May 2024
Available online: 25 June 2024

Keywords:
biodiesel, sunflower oil, copper oxide nanoparticles, diesel engine, thermal efficiency, brake-specific fuel consumption, engine performance

ABSTRACT

This study explores the impact of adding copper oxide (CuO) nanoparticles to biodiesel derived from sunflower oil on the performance of a diesel engine. Various concentrations of CuO nanoparticles were tested. Using a Korean-origin KiaBongo2701 Model 12 diesel engine, seven fuel types were examined, including pure diesel and biodiesel blends with different ratios. The effects of these blends and the performance of CuO nanoparticle additives were evaluated at various speeds and loads. Both mechanical mixing and ultrasonic devices were employed to prepare the fuel blends for comparison. Copper oxide nanoparticles significantly enhanced the performance of the D85B15 fuel blend, narrowing the performance gap with pure diesel. The results demonstrated that increasing the nanoparticle concentration led to a marked improvement in thermal efficiency at 1600 RPM, with D85B15PPM50 showing a 4.63% increase, D85B15PPM75 achieving a 6.41% improvement, and D85B15PPM100 experiencing a 7.54% boost. Diesel-like performance was attained using D85B15PPM100. D85B15's reduced calorific value raised fuel consumption, but nanoparticle integration improved brake-specific fuel consumption, especially at full load with 100 ppm copper oxide. The emissions tests showed that biodiesel blends containing nanoparticles produced less carbon monoxide and nitrogen oxides than the basic mix, reducing environmental impact. At the highest concentration (100 ppm), nanoparticles virtually equaled pure diesel performance, suggesting a way to produce biodiesel with equivalent performance and reduced environmental effects. These findings demonstrate the potential of nanoparticle additions to bridge the performance gap between biodiesel and conventional diesel and make biodiesel usage in diesel engines more sustainable and efficient.

1. INTRODUCTION

Efforts to find cleaner and more efficient fuels for diesel engines have prompted the investigation of different additives and mixtures. Biodiesel generated from sunflower oil has become an attractive alternative since it is sustainable and can reduce greenhouse gas emissions significantly [1, 2]. Researchers are using nanotechnology, namely copper oxide nanoparticles, to improve the efficiency of biodiesel mixes [3, 4]. Nanoparticles enhance the efficiency of combustion and decrease emissions, therefore tackling environmental issues and advocating for more sustainable energy sources in the transportation industry [5, 6]. The physiochemical features of biodiesel blends may be significantly enhanced by the presence of copper oxide nanoparticles, leading to a notable interest in their use [7, 8]. The researchers aim to enhance engine efficiency and reduce the ecological footprint by incorporating nanoparticles into biodiesel made from sunflower oil. Nanoparticles can boost combustion efficiency, improve thermal efficiency, decrease fuel consumption, and increase lubricity. This has the potential to cut engine wear and maintenance costs [9, 10].

Recently, several researchers have explored alternative fuels to reduce the use of diesel fuel and mitigate the pollution caused by diesel engines. Biodiesel and alcohol are attractive choices because of their renewable nature and ability to decrease greenhouse gas emissions [11-13]. Researchers are studying the qualities and combustion characteristics of alternative fuels such as biodiesel and alcohols to make it easier for them to be used in the transportation industry. These studies try to determine the most effective fuel formulas and mixes via thorough testing and analysis. The goal is to find environmentally friendly options while maintaining or enhancing engine performance. A key focus is on the viability of sunflower oil-derived biodiesel as a promising replacement for traditional petroleum-based diesel fuels. Azad et al. [14] explored the sustainability of biodiesel from mustard oil, testing blends from B20 to B50 in a diesel engine according to British standards. Yasin et al. [15] assessed the effects of palm oil methyl ester (PME) blends on diesel engine performance, demonstrating improved combustion and lower emissions without engine modifications. Moom et al. [16] studied fuel blends, including biodiesel-ethanol from waste cooking oil in a single-cylinder engine, noting a 7.26% increase in brake thermal efficiency and a 14.9% rise in brake-specific fuel consumption compared to pure diesel. Sayin Kul and

Kahraman [17] analyzed a diesel engine using a biodiesel and bioethanol blend, achieving nearly the same performance as traditional diesel. Şanli [18] examined biodiesel from microalgae in a four-cylinder engine, finding it comparable to conventional diesel, especially at higher speeds, and supporting its use in internal combustion engines.

Several researchers are focusing on the impact of nanoparticles in biodiesel to enhance diesel engine performance. This includes increasing efficiency and environmental compatibility by integrating nanoparticle additives into biodiesel blends. These studies examine the impact of nanoparticles on the efficiency of combustion, emissions, and overall performance of engines. They provide valuable insights for the development of more environmentally friendly diesel technology. Santhanamuthu et al. [19] conducted experiments using iron oxide nanoparticles in diesel fuel mixed with polenta oil. The results showed enhanced fuel efficiency and a 27% brake thermal efficiency (BTE) boost. Venu and Appavu [20] discovered that the presence of zirconium oxide nanoparticles enhances the fuel's calorific value and improves combustion efficiency. Al-Kayiem et al. [21] found that adding iron oxide nanoparticles improved the characteristics of fuel and the performance of engines while si multaneously decreasing emissions in a mixture of diesel and biodiesel. D'Silva et al. [22] observed that adding copper oxide nanoparticles to a biodiesel mix enhanced the engine's performance and decreased emissions. The most effective outcomes were achieved with higher concentrations of the nanoparticles. Uday and Simhadri [23] investigated the impact of titanium dioxide nanoparticles in bio-sesame oil blends. They observed significant enhancements in engine torque and a decrease in fuel consumption. The word by Sajeevan and Sajith [24], which focused on nanoparticles such as cerium oxide, demonstrated that these particles enhance the thermal efficiency of fuel by increasing oxygen levels. Shadidi et al. [25] and Zhang et al. [26] investigated the effects of several nanoparticle additions and indicated possible advantages in engine performance. They also emphasized the need for more studies on these additives' environmental and health implications. John et al. [27] used iron oxide nanoparticles to augment the generation of biodiesel from waste cooking oil. They found notable enhancements in combustion efficiency and thermal performance. Ağbulut et al. [7], Perumaland and Ilangkumaran [28] tested 1000 and 2000 ppm copper oxide (CuO) nanoparticles in diesel fuel in a diesel engine. These nanoparticles improved combustion efficiency, decreased hydrocarbon, carbon monoxide, and nitrogen oxide emissions, and boosted fuel heating value. Kalaimurugan et al. [29] tested a compression-ignition engine using CuO_2 nanoparticles (25, 50, 75, and 100 ppm) in a B20 diesel mix at different loads without altering the engine. All evaluated criteria revealed that CuO_2 improved combustion, engine performance, and emissions. Channappagoudra [30] examined the effects of incorporating copper oxide (CuO) nanoparticles at 25, 50, and 75 ppm concentrations into a DSOME-B20 diesel mix. The results showed that the 75-ppm blend had a notable positive influence on engine performance, efficiency, and emissions, surpassing the effects seen in the other blends. Chatur et al. [31] experimented on a regular diesel engine with adjustable compression ratios. They added copper oxide nano additives to a waste cooking oil methyl ester blend. This resulted in a 6.3% improvement in thermal efficiency and a 4.9% reduction in fuel consumption. Additionally, the experiment decreased CO and HC emissions by 26.1% and 4.3%, respectively. These findings collectively underscore the potential of nanoparticle-enhanced fuels to advance diesel engine efficiency and sustainability.

Governments worldwide are implementing stricter regulations on diesel engines due to their high levels of harmful emissions. Tackling these pollutants is a substantial problem for both engine makers and consumers. Given the circumstances, the development and utilization of sunflower oil biodiesel is imperative to diminish conventional energy use and mitigate environmental contamination. This study addresses a significant method to improve diesel engines' efficiency and decrease emissions using sunflower oil biodiesel infused with CuO nanoparticles. Biodiesel, mainly when produced from sunflower oil, is a sustainable and possibly less detrimental substitute for conventional diesel fuel. It frequently performs poorly compared to diesel. This work examines using copper oxide nanoparticles to address this performance difference. At increased nanoparticle concentrations and full load, thermal efficiency, fuel consumption, and emissions improved significantly. These findings suggest that this strategy might boost biodiesel's profitability and make fuels more sustainable.

2. METHOD AND MATERIAL

Table 1. Technical specifications of the diesel engine

Engine Specification		
No.	**Parameters**	**Engine**
1	Type of engine	J2 2701
2	Engine cylinder number	4
3	Cooling system	Water type
4	Piston Displacement	2,694cm3
5	Stroke	95mm
6	Bore	95mm
7	Engine oil type	SAE 10W-30
8	Nominal Output	59.656kW at 4,000rev/min.
9	Maximum Torque	164.75Nm at 2,400rev/min.

This study investigated the performance of various fuels in a Korean-made diesel engine, specifically the KiaBongo2701 model 12, featuring a 2.7-liter capacity, four-stroke design, and water-cooling system. The technical specifications of the engine are detailed in Table 1. The experiment occurred in the engineering workshop at the College of Agricultural Engineering Sciences, University of Baghdad, and utilized direct injection and water-cooling technology. To evaluate how different fuels impacted the engine, seven fuel types were tested:

a) Conventional diesel (D) served as the baseline for comparison.

b) Mixtures of conventional diesel and biodiesel:
   - D85 B15 (85% diesel, 15% biodiesel)
   - D90 B10 (90% diesel, 10% biodiesel)
   - D95 B5 (95% diesel, 5% biodiesel)

c) Biodiesel with copper oxide 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)
   - D85 B15 PPM 100 (85% diesel, 15% biodiesel with 100 ppm CuO nanoparticles)

The engine was tested at three speeds (1200, 1400, and 1600 rpm) across three progressive stages and load levels. The primary performance indicators examined were brake-specific fuel consumption and brake thermal efficiency.

Diesel fuel sourced from a local gas station in Salah al-Din/Iraq underwent three stages of preparation for the experiment. Initially, biofuels were produced, followed by blending these biofuels with diesel fuel. In the final stage, nanomaterials were added to the mixture. In the first stage of the experiment, the biofuels were synthesized through a specific transesterification process, leveraging catalytic activity to convert vegetable oil into usable biofuel. Initially, the vegetable oil was placed in a large metal jar and heated to a temperature range of 55℃ to 60℃. Then, potassium hydroxide was added as a catalyst to facilitate the chemical reaction. A mixture of methyl alcohol (methanol) and the catalyst was then introduced to the heated oil, ensuring the oil's temperature was maintained to prevent the alcohol from evaporating. The container was securely sealed to avoid any loss of alcohol through evaporation. Mixing was performed using an electric drill equipped with a fan blade, operating at a low speed for two hours. This facilitated the thorough integration of the oil with the catalyst and alcohol. After mixing, the mixture was left to sit for 24 hours, allowing the glycerin to precipitate. This glycerin was then separated using the traditional method, where it settled at the bottom of the jar and was removed, leaving the biofuel product above.

In the second stage of the experiment, the process involved mixing biofuels with diesel fuel. The diesel was combined with biofuels in three specific mixing ratios: 85% diesel to 15% biofuel (D85 B15) at a ratio of 8 liters diesel to 1.5 liters biofuel, 90% diesel to 10% biofuel (D90 B10) at a ratio of 9 liters to 1 liter, and 95% diesel to 5% biofuel (D95 B5) at a ratio of 9.5 liters to 0.5 liters. A graduated bowl was utilized to ensure precise measurements of each sample. After combining the components, the mixture was shaken vigorously for one minute to achieve a homogeneous blend.

In the third stage of the experiment, nanomaterial addition, each diesel fuel sample previously mixed with biofuels underwent further processing by incorporating copper oxide. The copper oxide was added in varying concentrations: 100 ppm, 75 ppm, and 50 ppm. These specific amounts were meticulously measured using a sensitive electronic balance to ensure precision. Three samples were prepared for each concentration to facilitate detailed analysis and comparison. The nanomaterial was blended with the fuel through ultrasound application via the GT SONIC apparatus depicted in Figure 1. This process aimed to disperse copper oxide particles uniformly within the fuel, ensuring a thorough mixture and minimizing their accumulation in the container.

The engine's velocity was electronically determined and monitored using a magnetic sensor connected to a speed-measuring apparatus on the experimental engine's control panel. The sensor was positioned close to the pilot wheel, detecting its rotation and converting this magnetic sensing into electronic signals. These signals were then displayed on the speed-measuring device depicted in Figure 1.

The North Refineries Company's Laboratories and Quality Control Department, specifically the Division of Evaluation and Analysis of Products and Materials, analyzed all fuel types utilized in the experiment. The outcomes detailing the properties of the tested fuels are depicted in Table 2.

Figure 1. Ultrasound and motor speed measuring devices

Table 2. The properties of the tested fuels

Test	D100	D95-B5	D90-B10	D85-B15	D85-B15-50PPM	D85-B15-75PPM	D85-B15-100PPM
Density@ 15ckg/L	0.845	0.831	0.833	0.837	0.832	0.8335	0.8336
API	41.6	38.7	38.3	37.5	38.2	37.9	38.2
Sulphur Content wt%	0.83	0.713	0.685	0.617	0.699	0.6952	0.6991
Cetane Index	53	54	54	52	54	53	54
Gross Calorific Value (kcal/kg)	10.95	10.87	10.86	10.85	10.86	10.867	10.870
Viscosity@40c	2.1	2.60	2.66	2.70	2.65	2.67	2.69

3. UNCERTAINTY ANALYSIS

An uncertainty analysis is essential for ensuring the tests' reliability, aiming to achieve the highest confidence level in the obtained results. This involves repeating the tests and ensuring accuracy in data collection. The variability in the performance factors' values is utilized to calculate uncertainty, typically expressed as the relative standard error percentage (Φ), as depicted in Eq. (1) [32].

$$\emptyset\% = \left(\frac{S}{Y}\right) \times 100 \tag{1}$$

Here, S represents the standard error, while Y denotes the average of the gathered data. The standard error is computed following equation [32]:

$$s = \frac{\alpha}{\sqrt{k}} \tag{2}$$

Here, α represents the standard deviation, and k represents the repeated measurements of the performance characteristics. The uncertainties associated with the measured parameters are outlined in Table 3.

Table 3. Uncertainties of the measured parameters

Parameter	Max. Value	Uncertainty
Speed (rpm)	1600	±0.09
BSFC (kg/kWh)	0.576	±1.50
BTE %	17.2	±1.42

4. RESULTS AND DISCUSSION

This section presents and discusses the experimental results of scientific tests conducted on the engine. Seven fuel mixtures were used, including conventional diesel fuel (D100) and various blends of sunflower biodiesel (D95 B15, D85 B15, D90 B10). Copper oxide particles were added to the D85 B15 mixture to enhance its performance and bring it closer to that of pure diesel. Thermal performance, particularly brake efficiency and fuel consumption, was the primary focus of the research. The data are visualized through graphs, and performance charts were meticulously analyzed to understand the performance characteristics of the diesel engine under different conditions, including fuel mixtures and nanoparticle concentrations, across various speeds and loads. The tests were conducted three times to ensure accuracy and minimize errors.

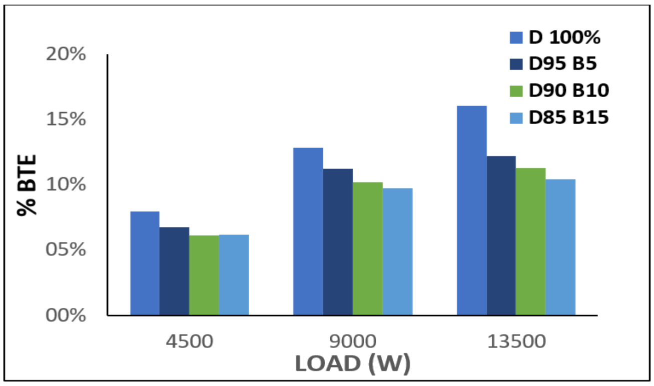

Figure 2. BTE vs. engine load with different mixtures at 1200rpm

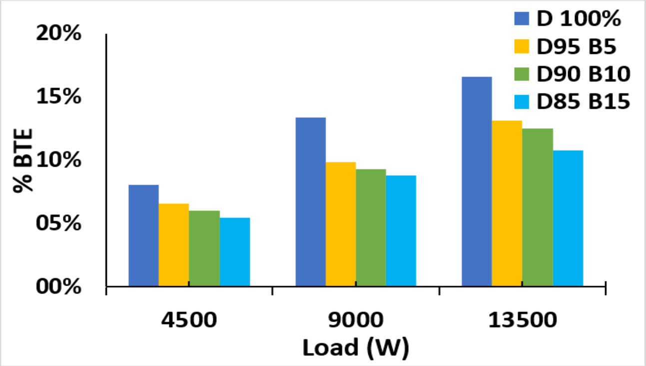

Figure 3. BTE vs. engine load with different mixtures at 1400rpm

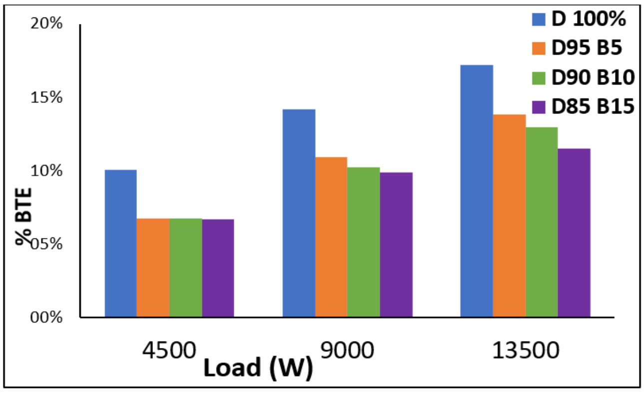

Figure 4. BTE vs. engine load with different mixtures at 1600rpm

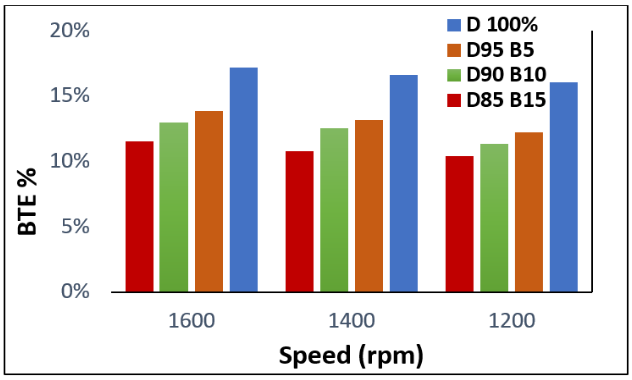

Figure 5. BTE rated for fuel mixture with engine speeds at load 13500W

Figures 2-4 illustrate the relationships between engine load and Brake Thermal Efficiency (BTE) for different blends. Overall, adding sunflower biodiesel to diesel decreases engine BTE across rotational speeds of 1600rpm, 1400rpm, and 1200rpm. This decline in BTE can be primarily attributed to the lower calorie content of mixtures containing 5%, 10%, and 15% sunflower biodiesel compared to pure diesel.

It is observed from Figure 5 that the BTE values for blends D85B15, D90B10, and D95B15 at speeds of 1200, 1400, and 1600rpm are slightly lower than those of pure diesel fuel. This decrease is attributed to the reduced calorific value and cetane number resulting from adding vegetable sunflower oils compared to pure diesel. Previous research consistently supports the notion that biodiesel blends exhibit lower BTE than pure diesel [33-36].

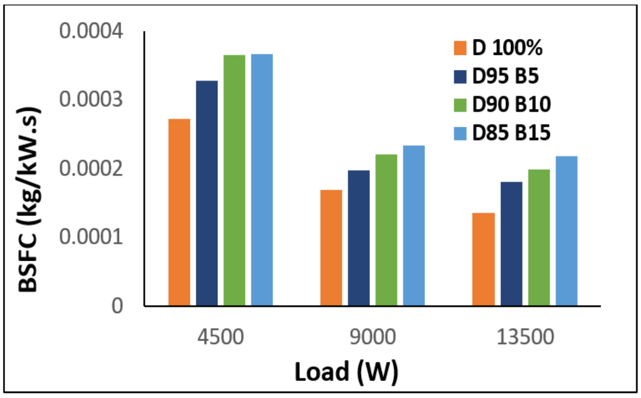

Figure 6. BSFC vs. engine load in different mixtures at 1200rpm rotational speed

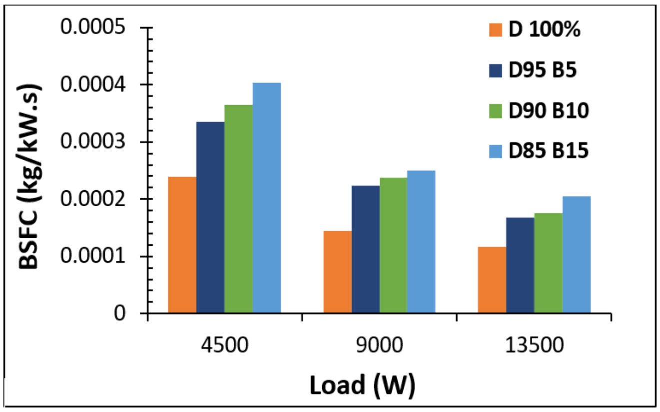

Figure 7. BSFC vs. engine load in different mixtures at 1400rpm rotational speed

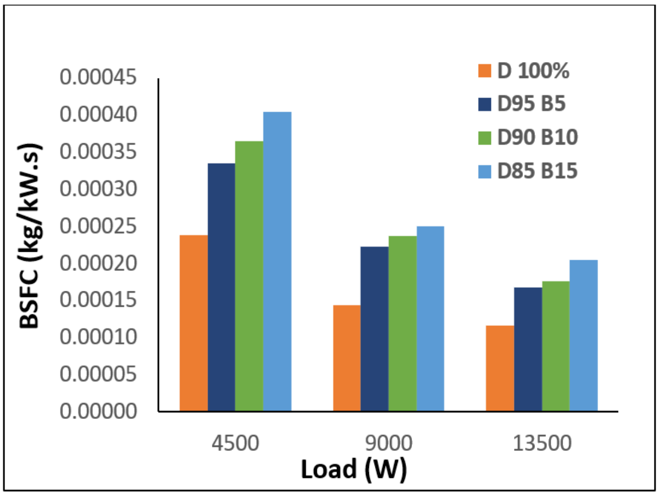

Figure 8. BSFC vs. engine load in different mixtures at 1600rpm rotational speed

Figures 6-8 illustrate the relationship between engine loads and brake-specific fuel consumption (BSFC) at speeds of 1200rpm, 1400rpm, and 1600rpm. The graphs reveal a clear trend: as engine load increases, fuel consumption rises. Notably, excess sunflower oil-derived biodiesel leads to increased fuel consumption. This change is influenced by the calorific value of both biodiesel and diesel. Interestingly, true diesel consistently exhibits the lowest BSFC values across all engine loads due to its inherent fuel characteristics. Similar trends were observed in a previous study [37].

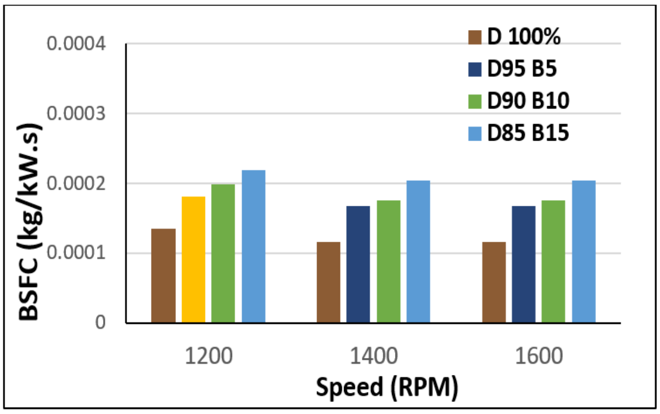

Figure 9. BSFC rated for fuel mixture with engine speeds at load 13500W

Figure 9 illustrates how brake-specific fuel consumption (BSFC) varies as the engine operates at speeds of 1200rpm, 1400rpm, and 1600rpm, with a load of 13500W. All fuel mixtures exhibit a consistent trend, with the lowest BSFC values occurring at 1600rpm and the highest at 1200rpm. Notably, diesel consistently achieves the lowest BSFC levels across the entire speed range. Researchers have observed a similar deviation in BSFC for sunflower biodiesel compared to diesel [27]. This discrepancy is attributed to the lower calorific value of biodiesel. Compromising measures are necessary to achieve the same energy output due to this lower calorific value. As anticipated, the addition of biodiesel to diesel leads to increased fuel consumption, dependent on load and operating conditions.

Mixing biodiesel with CuO nanoparticles increased brake thermal efficiency (BTE), as illustrated in Figures 10-12, in comparison to diesel blended with biofuels (D85B15) across engine speeds of 1200rpm, 1400rpm, and 1600rpm. The addition of copper oxide nanoparticles notably and reasonably enhanced brake thermal efficiency by boosting brake force and increasing heat transfer efficiency. This enhancement can be attributed to the high surface-to-volume ratio of nanoparticles, which promotes efficient fuel oxidation, and the excellent conductivity of copper oxide nanoparticles, which facilitates enhanced heat transfer, thereby contributing to improved brake thermal efficiency. These observations align with the findings reported by Man et al. [35].

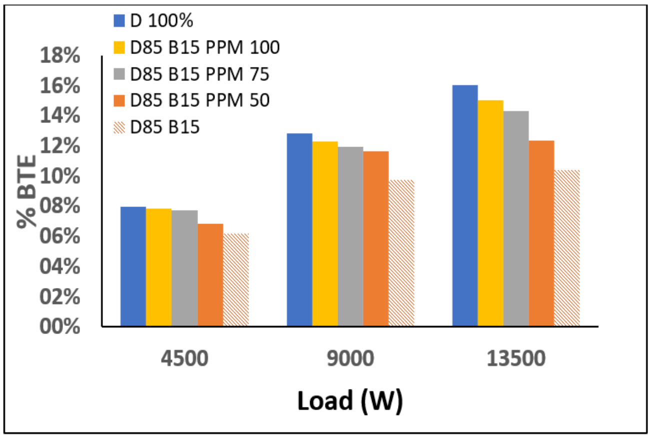

Figure 10. BTE offers different nano dosages compared to elegant diesel and a combination of 15% biodiesel at 1200rpm

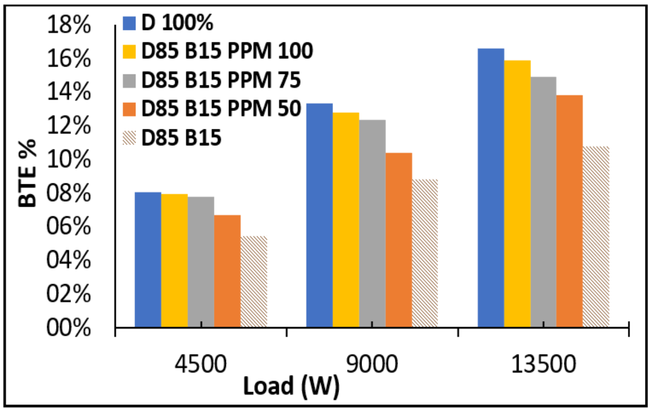

Figure 11. BTE variation with comparison of nanodoses to pure diesel and a mixture of 15% biodiesel at 1400rpm

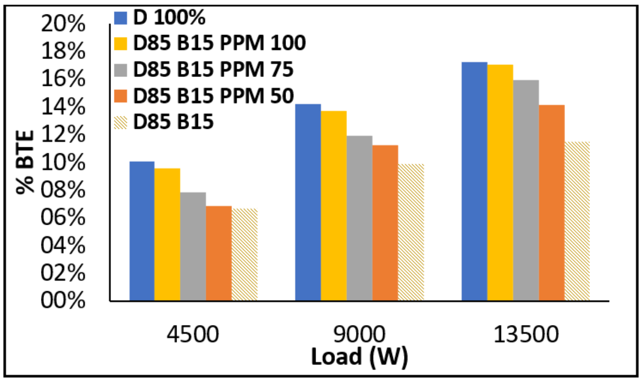

Figure 12. Variation in BTE appears at a different nano dose compared to the pure diesel and 15% biodiesel blend at 1600rpm

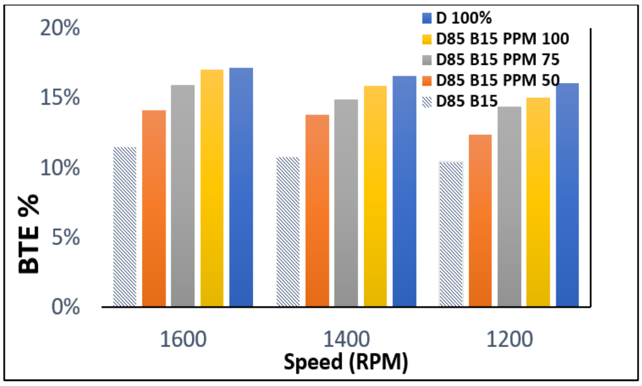

Figure 13. BTE rated for fuel mixture with engine speeds at load 13500W

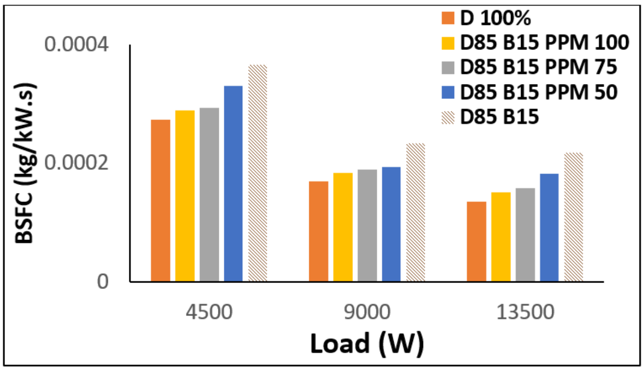

Figure 14. Change in BSFC appears using varying nano quantities of the diesel-biodiesel mixture at 1200rpm

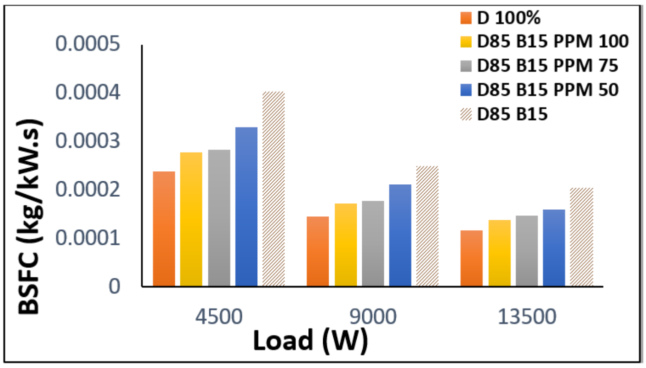

Figure 15. Change in BSFC appears using varying nano quantities of the biodiesel mixture at 1400rpm

The brake thermal efficiency (BTE) was calculated while the engine operated under a load capacity of 13,500 watts and variable motor speeds of 1200rpm, 1400rpm, and 1600rpm, as depicted in Figure 13. As the engine speed increases, BTE improves due to more work being done with lower fuel consumption. The highest BTE percentage occurs at 1600rpm, reaching 17.20% for pure diesel. When CuO nanoparticles are added to the fuel mixture, the BTE values are 17.06%, 15.93%, and 14.15% at different nanoparticle concentrations. Notably, the addition of nanoparticles enhances overall engine efficiency. These nanoparticles act as oxidizing agents, leading to better thermal efficiency and an overall increase in engine performance.

Figures 14-16 illustrate the relationship between brake-specific fuel consumption (BSFC) and engine load. The base fuel mixture, known as D85B15 (a blend of 15% biodiesel and 85% pure diesel), was enhanced with nano copper oxide particles at concentrations of 50, 75, and 100 ppm. The addition of nanoparticles led to improved BSFC, especially as nanoparticle concentration increased. Optimal outcomes were achieved when the system operated at maximum capacity. Notably, adding 100 ppm of copper nanooxide resulted in a significant boost in fuel efficiency, allowing the engine to generate more power with less fuel consumption. Overall, including nanoparticles enhanced combustion efficiency compared to fuel combustion without copper nanooxide. Similar findings were also reported by Atmanlı et al. [36].

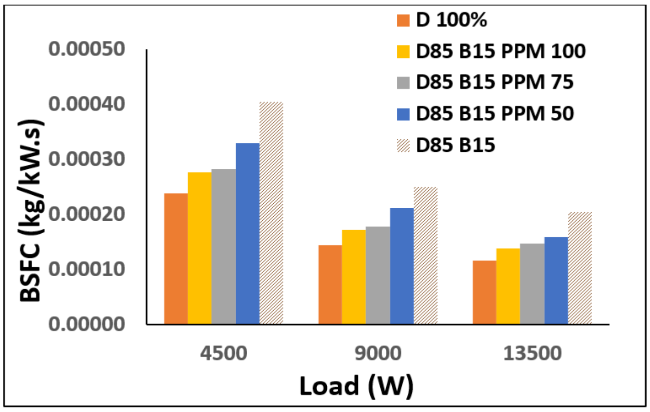

Figure 16. Variation in BSFC at different nano doses of diesel and biodiesel blend at 1600rpm

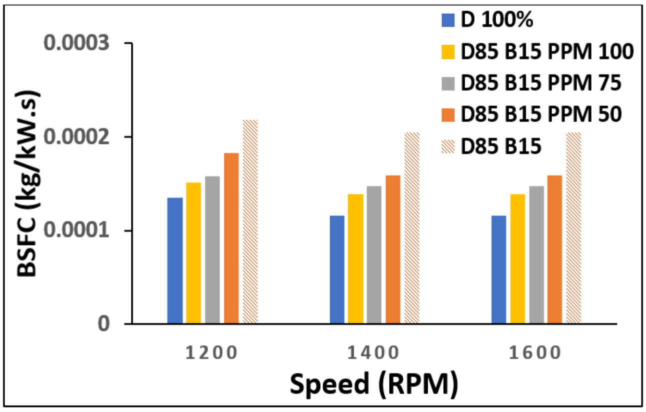

Figure 17. BSFC rated for fuel mixture with engine speeds at load 13500W

The engine's Brake-Specific Fuel Consumption (BSFC) was evaluated under a 13,500-watt load, with speeds ranging from 1200 to 1600rpm, as depicted in Figure 17. Optimal performance was observed at 1600rpm. Notably, adding 50ppm, 75ppm, and 100ppm of copper nanoparticles significantly improved fuel efficiency, enabling the engine to generate more power while consuming less fuel. Overall, including nanoparticles enhanced combustion efficiency compared to fuel combustion without copper nanoparticles, consistent with findings from prior research [36].

All fuel blends exhibit an increase in CO_2 emissions with an increase in engine speed (RPM), as seen in Figure 18. This is consistent with the general understanding that higher engine speeds result in more complete combustion, thus producing more CO_2. Pure diesel shows the lowest CO_2 emissions across all RPM ranges. At 1600 RPM, it reaches about 0.064%. The D85B20 biodiesel blend shows higher CO_2 emissions than pure diesel and the CuO-added blends. It peaks at around 0.10% at 1600 RPM. Adding CuO nanoparticles to the biodiesel blend (D85 Bi15) seems to increase the CO_2 emissions slightly than the pure diesel. This could be due to enhanced combustion efficiency provided by the catalytic properties of CuO, resulting in more complete combustion and, therefore, higher CO_2 output.

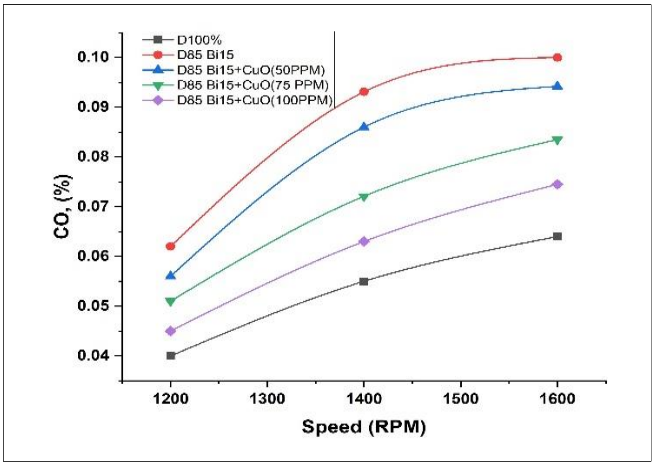

Figure 18. Variation of CO with engine speeds at load 13500W

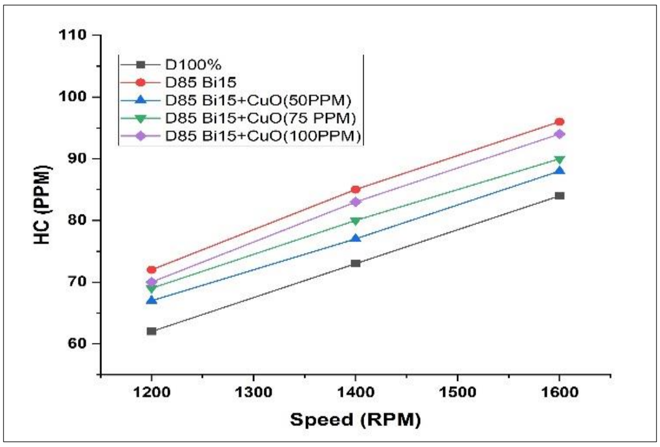

Figure 19. Variation of HC with engine speeds at load 13500W

Figure 19 shows that CuO nanoparticles reduce HC emissions in biofuel compared to diesel. This reduction is due to the homogeneous mixing of fuel blends with air, increased surface/volume ratio aiding complete combustion, and CuO nanoparticles acting as oxidation catalysts [28, 38-40]. At 1600 RPM, D85B15CuO100 emits 11.43% less HC than diesel, similar to D80B20 fuel blends. Including 15% biodiesel (D85 Bi15) leads to higher HC emissions levels than 100% diesel (D100%) at all speeds. This may be due to the distinct combustion properties of biodiesel. Adding CuO nanoparticles to biodiesel blends significantly decreases HC emissions, and larger concentrations of CuO result in even more significant reductions.

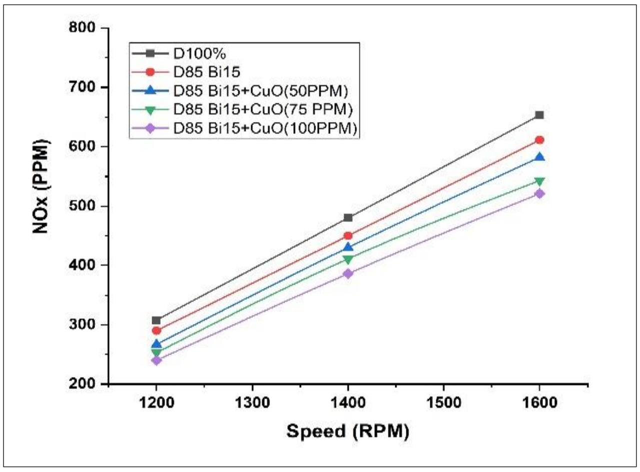

Figure 20. Variation of NO_x with engine speeds at load 13500W

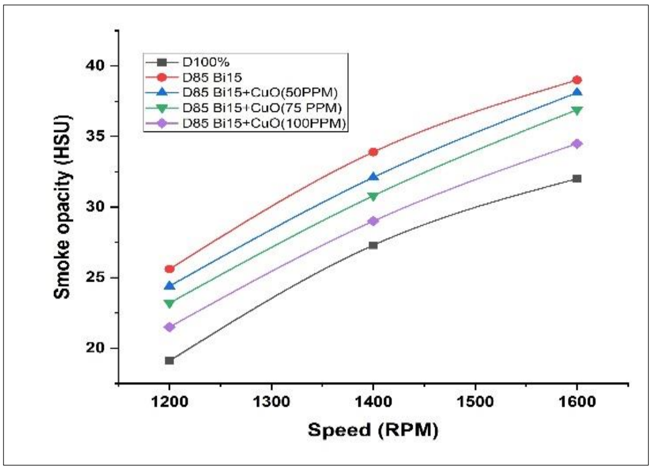

Figure 21. Variation of smoke opacity with engine speeds at load 13500W

Figure 20 depicts the correlation between nitrogen oxide (NO_x) emissions, measured in parts per million (PPM), and engine speed, measured in revolutions per minute (RPM), for various fuel mixtures. NOx emissions positively correlate with engine speed, rising from 1200 RPM to 1600 RPM across all fuel mixes. This phenomenon is anticipated since higher engine speeds often lead to elevated combustion temperatures, which in turn cause an increase in the generation of NOx. At all engine speeds, using 15% biodiesel (D85 Bi15) results in lower NO_x emissions than using 100% diesel (D100%). The decrease in NO_x emissions may be ascribed to the oxygen content in biodiesel, which facilitates enhanced combustion and thus reduces NO_x emissions. Adding CuO nanoparticles to biodiesel blends leads to an additional decrease in NO_x emissions [28]. The decline is more noticeable with greater concentrations of CuO. At 1600 RPM, D85B15 CuO100 emits

521 ppm NO_x, a 17.3% reduction compared to the 611 ppm from the D85B15 blend.

Figure 21 illustrates that smoke emissions from CuO nanoparticle additive fuel blends are lower than those from diesel. At 1600 RPM, smoke emissions were 39 HSU for D85B15, 34.5 HSU for D85B15 CuO100, and 32 HSU for diesel. The reduction in smoke emissions for D85B15 CuO100 compared to D85B15 is attributed to the high surface-to-volume ratio of CuO nanoparticles, which improve mixture formation, evaporation, and ignition characteristics, leading to a shorter ignition delay. This finding aligns with other research [28, 41-43], showing a 13.04% reduction in smoke emissions for B20CuO100 compared to B20.

5. CONCLUSIONS

In an experimental investigation, the performance of sunflower oil-based biodiesel as an eco-friendly fuel alternative was examined, with a specific focus on its effects on engine efficiency. Blends comprising higher concentrations of sunflower biodiesel demonstrated diminished efficiency, necessitating greater fuel consumption for equivalent power output than pure diesel. Nevertheless, introducing minute copper oxide (CuO) nanoparticles notably improved efficiency. This discovery implies that nanoparticles could bolster the feasibility of sunflower biodiesel for future utilization. In conclusion, the study produced encouraging findings, outlined as follows:

- Biodiesel blends (D85B15, D90B10, D95B15) show lower thermal efficiency than pure diesel due to their reduced calorific value and cetane number.
- Higher engine speed leads to lower fuel consumption (BSFC) for all fuels, with the most significant benefit occurring at 1600rpm.
- Pure diesel consistently has the lowest BSFC compared to sunflower biodiesel blends due to its higher calorific value. This necessitates increased fuel consumption with biodiesel blends despite similar energy output.
- Adding copper oxide nanoparticles (50-100ppm) to a biodiesel blend (D85B15) significantly improved brake-specific fuel consumption (BSFC), especially at high engine loads.
- While biodiesel blends, such as D85 Bi15, generally produce lower NOx emissions levels than pure diesel (D100%), adding CuO nanoparticles further decreases these emissions.
- Utilizing nanoparticles significantly decreased carbon monoxide, indicating a dual advantage of improved performance and less environmental impact.
- Adding copper oxide nanoparticles (50-100 ppm) significantly enhanced fuel efficiency at all speeds, enabling more power generation with less fuel consumption than fuel without nanoparticles.

Future studies might examine nanoparticle materials like titanium dioxide or iron oxide, which may have different or better advantages than CuO. Studying nanoparticles in biodiesel from additional plant sources or waste oils might broaden its use and enhance blends for certain engine types or operating circumstances. Research into their long-term impacts on engine wear and maintenance and lifetime environmental impact is essential for commercial and industrial use of nanoparticle additives.

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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