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Original Research Article

Exploring the role of nanoparticle additives in reducing emissions in compression ignition engine

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Abstract: The paper discusses the growing environmental issues caused by vehicle emissions, leading many countries to tighten their emission standards to reduce the harmful gases released by motor vehicles. This is especially important as urbanization has increased, leading to more consumption of petroleum products. As a result, there is a growing need for cleaner, more sustainable fuel alternatives. Biodiesel has been recognized as a potential solution since it is renewable, non-toxic, and less environmentally harmful than traditional diesel. The study in question explores how adding biodiesel and nanoparticles affects diesel engine performance, particularly in terms of noise and particulate matter emissions (small particles of pollution). The research was carried out using a compression ignition engine (like those found in diesel vehicles) under constant RPM (revolutions per minute) and variable loads (changes in engine stress or power requirements). The results showed that when biodiesel was blended with nanoparticles and used as fuel, there was a noticeable reduction in noise levels, carbon dioxide, and particulate matter emissions compared to regular diesel. This suggests that biodiesel, especially when enhanced with nanoparticles, can effectively lower the harmful effects of diesel engines on the environment, offering a greener and quieter alternative.

Keywords: Biodiesel, Nanoparticles, Particulate matter, Noise emissions, Compression ignition engine, Vehicle emissions, Emission standards, Harmful gases, Petroleum products.

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1. Introduction

Many studies suggest that the world is facing an energy crisis due to the depletion of conventional energy sources and their active role in global climate change and increasing CO_2 emissions to the atmosphere (Salam *et al.*, 2024). Therefore, biofuel is considered an alternative to overcome this global issue. A study found that biodiesel had similar engine performance to diesel fuel, with a slight decrease in power output (Raqeeb & Bhargavi, 2015). Reducing carbon emissions is one of the primary motivations for adopting biodiesel as an alternative fuel. Several studies have investigated the carbon emissions of biodiesel compared to conventional fuels. Bhangwar *et al.* (2024) found that using biodiesel resulted in lower carbon emissions than diesel fuel. The study reported up to 24% reduction in CO_2 emissions when using biodiesel.

Similarly, a study by Udayakumar (2020) reported a reduction of up to 20% in CO_2 emissions when using biodiesel compared to conventional diesel fuel. The study by Chuangbin (2021) compared the engine performance of biodiesel and diesel fuel and found that the use of biodiesel had a negligible effect on engine performance in terms of power and torque output. The study also found that biodiesel had similar engine performance to diesel fuel, with a slight decrease in power output. (Farvardin *et al.*, 2022) investigated the engine performance of a diesel engine using biodiesel and diesel fuel blends. The study reported that the use of biodiesel resulted in higher brake-specific fuel consumption compared to diesel fuel

Similarly, Temizer and Eski (2020) studied a diesel engine's performance and emissions using biodiesel and diesel fuel blends. The study found that the use of biodiesel resulted in lower NOx emissions, but higher particulate matter emissions compared to diesel fuel. The study also reported a slight decrease in power output and engine efficiency when using biodiesel. Varun and Chauhan (2013) analysed the performance of a 4-stroke water-cooled diesel engine using biodiesel produced from different blends of coconut oil and cotton seed oil. Their study showed that blend B10 of coconut oil was one of the finest alternative fuel replacements for diesel fuel running in a four-stroke water-cooled diesel engine. Natesan *et al.* (2022) performed an experimental study to analyse the performance of a single-cylinder four-stroke diesel engine using biodiesel produced from Mahua oil methyl ester blended with nano-metal additives of titanium dioxide. The addition of 150 ppm of titanium dioxide improved the combustion efficiency and reduced the emission characteristics. Metal additives of titanium dioxide can be a promising alternative source of energy for reducing greenhouse gas emissions and mitigating environmental impacts (Bhangwar *et al.*, 2022). Furthermore, the sound pressure level (or noise) was measured from various locations around the engine (back, front, and left side) under different loads. The study found that a fuel blend consisting of 25% biodiesel and 75% diesel, known as B25, consistently produced less noise than pure diesel (D100) in all measured cases. This indicates that biodiesel blends improve fuel efficiency and reduce noise pollution, making them a better alternative in terms of both environmental and operational performance (Bhangwar *et al.*, 2024).

Carbon deposits on engine components, such as pistons and valves, are a significant concern because they reduce engine efficiency and increase maintenance costs. By testing these blends, the study aimed to determine whether using biodiesel and clove oil could mitigate these effects compared to conventional diesel. Including clove oil is particularly interesting because of its natural properties that may help reduce engine wear and tear. The tests also measured noise emissions, providing a comprehensive view of how these additives influence engine performance and environmental impact (Bhangwar *et al.*, 2022). To further assess the effects of these fuels on engine wear, the engine was operated for 100 hours on each fuel sample. Every 25 hours, elemental analysis was conducted to measure the concentration of various metals in the engine's lubricant oil. The results showed lower concentrations of harmful metals like lead, copper, nickel, and cadmium in engines running on biodiesel and biodiesel with clove oil compared to those running on pure diesel (Nair *et al.*, 2021).

Jeyakumar *et al.* (2019) study looked at the effect of clove oil's inherent antioxidants on the biodiesel made from used cooking oil's oxidative stability. Using the ASTM D7545 standard procedure, the oxidative stability of biodiesel was assessed by adding antioxidants at concentrations of 1,000, 2,000, and 3,000 ppm and contrasting them with the chemical antioxidant BHT at the same levels. Antioxidants raised the specific fuel consumption and decreased the thermal efficiency of B20 biodiesel blends in engine tests. However, the antioxidants increased hydrocarbon emissions while improving smoke opacity and CO_2 emissions. Compared to B20 without antioxidants, BHT was more effective at lowering NO emissions, although it increased CO emissions. It was discovered that CEO-blended fuel had improved emissions and better engine performance than the TEO-blended fuel (Uğuz *et al.*, 2023).

Due to its high antioxidant qualities, clove oil was found as a natural ingredient for honge oil biodiesel. According to engine tests, adding clove oil to biodiesel dramatically lowered NOx emissions without changing the engine's physical components. Additionally, the clove oil enhanced the biodiesel's oxidation stability (Uğuz *et al.*, 2022). Biodiesel fuel and fuel additives are advised to address environmental concerns and maintain engine performance. Clove oil can be used as a bio-additive to enhance fuel characteristics and lower emissions because it includes eugenol and other chemicals with antioxidant effects. According to studies, adding clove oil to biodiesel-diesel fuel can dramatically lower emissions of air pollutants including CO and HC, while enhancing engine performance and fuel combustion reactivity (Kapilan *et al.*, 2022).

Clove oil was investigated as a natural, non-toxic, and sustainable additive for honge oil biodiesel to reduce NOx emissions without altering the engine hardware. Engine tests showed that adding clove oil significantly reduced engine NOx emissions and enhanced the oxidation stability of honge oil biodiesel (Elaine *et al.*, 2022; Natesan *et al.*, 2021). The findings demonstrated that adding clove oil at various volume percentages reduced fuel use, with 0.5% of clove oil causing the greatest decrease. According to the study, additional research is needed to determine whether clove oil and citronella oil may be combined as additives to lower fuel usage while reducing the possibility of engine corrosion. In order to reduce Indonesia's rising fuel consumption, the study emphasizes the potential of essential oils as bio-additives for increasing fuel economy (Turki *et al.*, 2021). At doses of 0.25% and 0.5%v/v, three essential oils—clove leaves oil, patchouli oil, and citronella oil—were employed. The oxidative stability was noted at two distinct storage temperatures, namely 27°C and 60°C. The addition of 0.5% clove oil at a storage temperature of 27°C, with a Composite Performance Index (CPI) value of 339.75, an acid number of 0.68 mg KOH/g, a peroxide number of 17.54 mg O2/100 g, the kinematic viscosity of 4.48 cSt, and a rancimat test of 12.91 hours, was the most effective treatment, according to the results (Biberci, 2023).

Clove bud oil and cinnamon leaf oil substantially improved the induction period of Pongamia biodiesel, indicating that essential oils containing higher amounts of eugenol could be used for this purpose. Additionally, the effectiveness of clove bud oil in reducing Nitric oxide emission from a diesel engine was studied, and it was found that the addition of 2% v/v clove bud oil to Pongamia biodiesel resulted in a significant reduction in Nitric oxide emission without affecting engine performance or other emissions (Rahman *et al.*, 2019a). The Compression Ignition (CI) engines' performance, combustion properties, and emission parameters are a result of essential oils and their mixtures. Essential oils have been demonstrated to enhance engine performance and lower emissions of carbon monoxide, hydrocarbons, and particulates that are similar to those of pure diesel. However, nitrogen oxide emissions have reportedly been rising because of their lower cetane number and increased oxygen content. Combining them with biodiesel or diesel allows essential oils to be used in CI engines. The essential oil industry's rapid rise increases the likelihood of their use in the transportation and agricultural sectors (Chellachamy *et al.*, 2019). According to the results, adding 0.5% clove terpene resulted in the greatest reduction in particulate matter at 38.26%, 62.85%, and 91.11% at 4, 6, and 14-m filtration, respectively. Turpentine was added, and this caused the water content to decrease the most, from 312 to 282 ppm. These results imply that the bio-additives derived from essential oils may be able to solve the problems associated with the use of B30 biodiesel (Rusli *et al.*, 2022).

According to the study, the terpene chemicals in clove oil served as a mediator between the bio-additive and base fuel, enhancing combustion performance, including quick burning and reduced ignition delay. The bio-additive was given oxygen to produce the most significant overall heat release, resulting in lower smoke, CO, and HC emissions. However, adding eugenyl acetate did not linearly improve combustion efficiency despite the increase in oxygen supply. Finally, it was discovered that the oxygen content significantly impacted NOx emissions (Gamayel *et al.*, 2020). It was found that clove oil, which primarily contains eugenol, outperformed turpentine oil in lowering brake-specific fuel consumption and exhaust pollutants. It has been demonstrated that eugenol undergoes an ester reaction to produce eugenyl acetate, which has greater oxygen content and a bulkier structure, improving fuel combustion. The research was divided into three stages: characterization of the bio-additive using a GCMS and FTIR spectrophotometer, composition optimization, and a laboratory performance test on a one-cylinder engine. The findings of the study showed that the BSFC could be decreased, exhaust emissions could be decreased by clove oil, eugenol, and eugenyl acetate, and oxygen enrichment can improve fuel combustion even more (Rahman *et al.*, 2019b).

It was determined that clove oil caused the gasoline blend to burn unevenly and experience more micro explosions. This results from clove oil's volatility, which makes it easier for bubbles to form inside the droplet and causes ejection and secondary atomization outside the droplet. According to the study's findings, adding clove oil to blends can change the way combustion occurs and boost micro explosion, which may have an impact on engine output and emissions Singh, (Garima *et al.*, 2023). However, all essential oil blends released more particle matter at all loads. The results indicate that essential oils can potentially be employed as bio-additives in diesel engines, with eucalyptus and orange oils showing the most promising qualities (Gamayel *et al.*, 2020).

From the literature review, various nanoparticles have been used to enhance engine performance, increase engine life, and reduce pollution. However, in this research, iron oxide nanoparticles are used to analyse engine performance and emissions, aiming to increase engine life and reduce environmental problems.

2. Research methodology

To achieve the objectives of the research has been given. Three fuel samples were tested in the diesel engine, such as D100, B20 (80% Diesel fuel +20% biodiesel) and feO3 (97% biodiesel blended fuel + 3 % iron oxide). In this research, three different factors, the performance analysis of the engine, noise emission level and carbon emission level, have been investigated. Fuel properties were determined based on ASTM (American Society of Testing Materials) standards. Moreover, in this work, performance and sound pressure level tests were determined at different loads and at constant speeds.

Figure 1: Flow diagram of research methodology

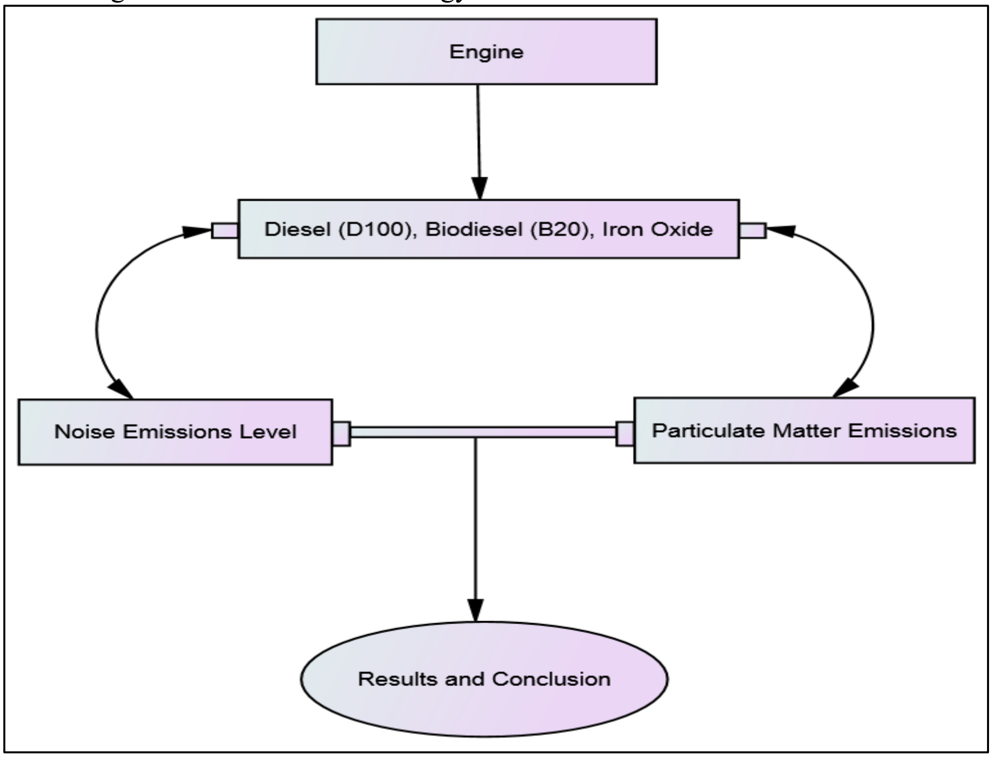
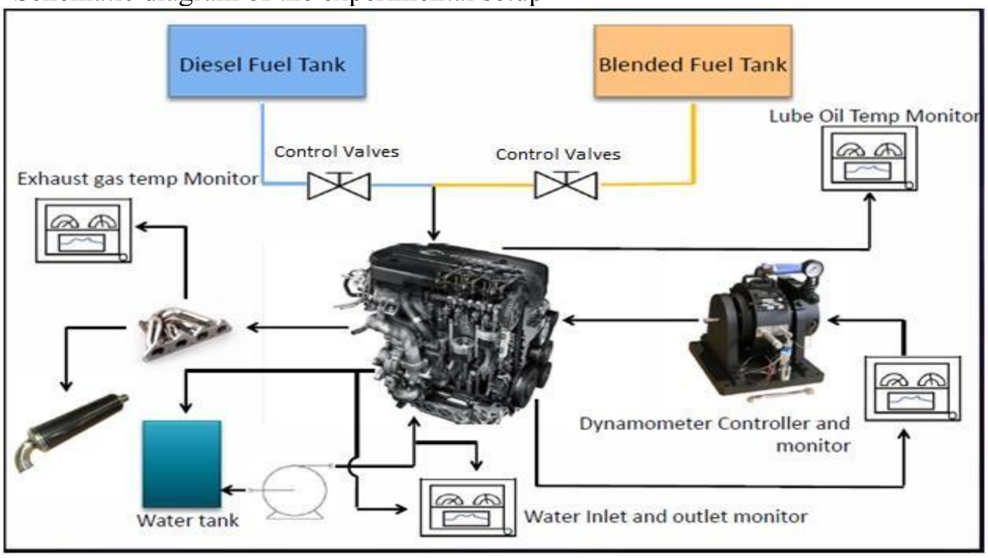


Figure 2: Schematic diagram of the experimental setup



2.1. Noise emission level

In this research, the Sound Pressure Level (SPL) of a Compression Ignition (CI) engine was evaluated using biodiesel blended with nanoparticles as additives. The sound pressure level was analysed under constant engine speed (rpm) with varying loads, allowing for an assessment of how engine load influences noise levels. The SPL measurements were taken from three distinct directions—front, back, and left of the engine—to ensure a comprehensive analysis of the sound profile around the engine.

Three microphones were placed 1 meter away from the engine test bed in the specified directions to collect precise sound data. This setup ensured that the measurements reflected sound propagation in a consistent manner around the engine. The sound pressure levels were recorded using a sound pressure level dB meter, which is a specialized device used to measure sound intensity in decibels (dB). Figure 1 likely provides a schematic illustration of the microphone arrangement around the engine. Figure 2 offers specific details about the equipment, such as the model of the sound level meter and microphones used, their sensitivity range, and calibration methods. This setup was designed to ensure the accuracy and reliability of the sound pressure level measurements, which are crucial for analysing the noise impact of using biodiesel and nanoparticles in the CI engine.

2.2. Particulate Matter (PM) emissions

In this analysis, the PM emissions of a CI engine were examined when using biodiesel blended with nanoparticles as additives. The study focused on measuring particulate emissions while maintaining a constant engine speed (rpm) but varying the engine load to observe how load changes impact PM emissions. Particulate matter emissions, which consist of tiny particles resulting from incomplete combustion, are a significant environmental concern, especially in diesel engines. Biodiesel, with its cleaner combustion properties and nanoparticles, can influence the combustion process and emission characteristics. Nanoparticles can improve combustion efficiency by enhancing the fuel-air mixture and promoting better burning, potentially reducing particulate formation.

The analysis aimed to capture PM emissions across different load conditions while keeping the engine's rpm constant. As the load on the engine increases, the combustion characteristics change, affecting the formation and release of particulate matter. By monitoring these emissions at variable loads, the study could assess the effectiveness of the biodiesel-nanoparticle blend in reducing particulate emissions compared to conventional diesel. This analysis provides insights into how biodiesel and nanoparticles can work together to lower particulate emissions, particularly in high-load situations where engines typically produce more PM due to incomplete combustion. This research is crucial for understanding fuel additives' role in improving CI engines' environmental performance, especially in reducing harmful pollutants like particulate matter.

3. Results and analysis

3.1. Noise emissions level

The SPL of a CI engine was measured under various load conditions using three types of fuel: pure diesel (D100), a biodiesel blend (B20), and biodiesel with nanoparticles. Noise levels were recorded at three specific positions: the front, back, and left sides of the engine, each positioned 1 meter from the piston head (Bhangwar *et al.*, 2024).

Figure 3 shows that the engine running on D100 diesel fuel produced higher noise emissions compared to the B20 biodiesel blend. Moreover, when nanoparticles were added to the biodiesel blend, noise levels at the front of the engine decreased compared to both biodiesel and diesel fuels. Notably, lower sound levels were observed under initial loads. Slight differences in friction were also noted when using biodiesel fuel at medium load conditions, contributing to these variations in noise levels.

Figure 3: Sound pressure at the front position

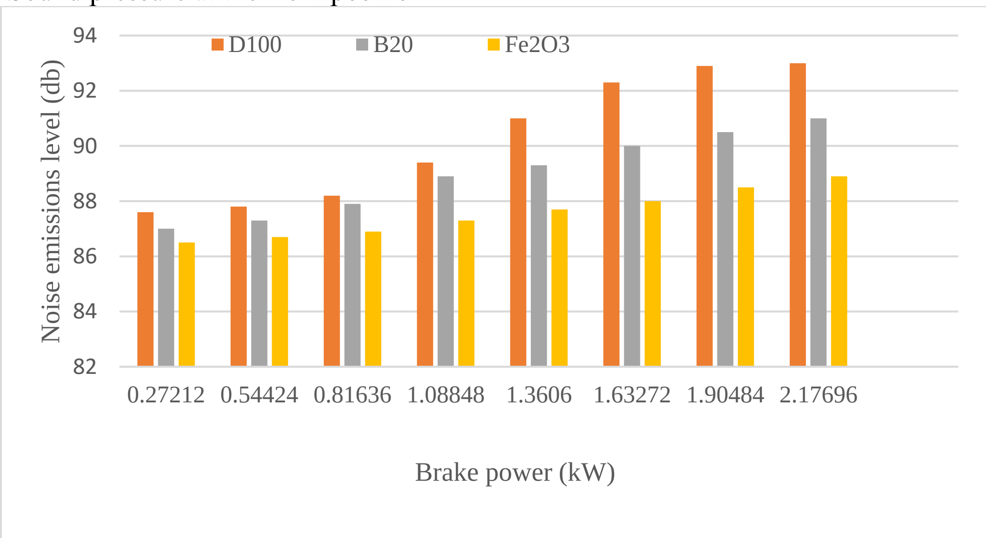
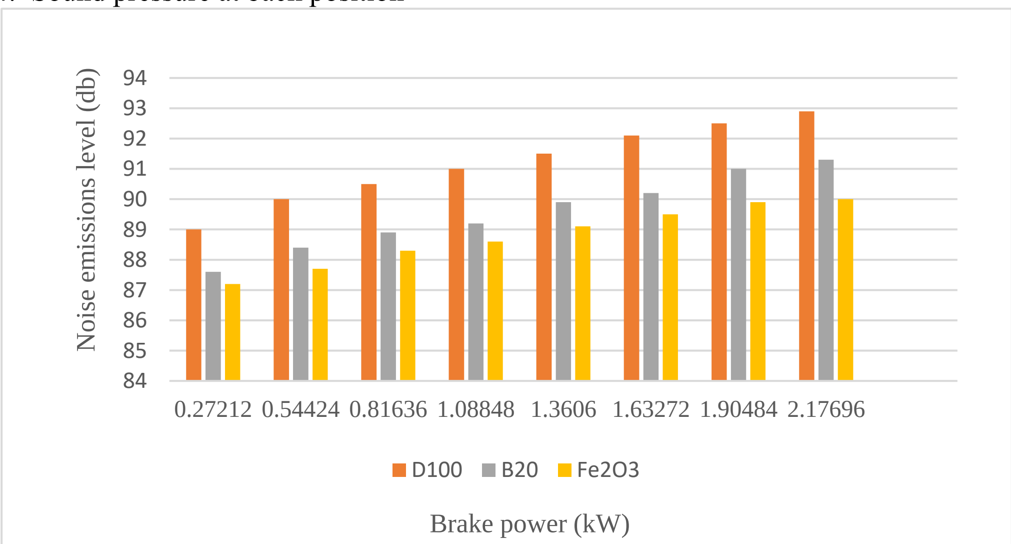


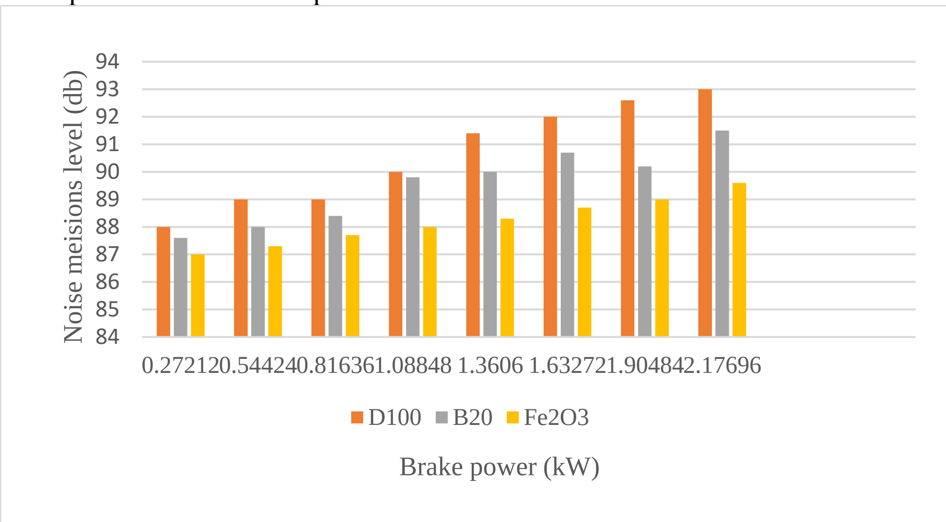
Figure 4 demonstrates that the sound pressure analysis at the back of the engine revealed higher noise emissions when using D100 diesel fuel compared to the B20 biodiesel blend. Additionally, including nanoparticles in the biodiesel blend further reduced noise levels at the back of the engine compared to both biodiesel and diesel fuels.

Figure 4: Sound pressure at back position



The engine's Sound Pressure Level (SPL) was measured at different positions, including the left side, under various load conditions and using other fuels. The analysis shows that D100 diesel fuel generated higher noise emissions than the B20 biodiesel blend. However, when nanoparticles were added to the biodiesel blend, the noise levels at the left side of the engine were further reduced. This suggests that nanoparticles help dampen the noise, likely by enhancing the combustion process or reducing mechanical friction, which results in lower sound emissions than diesel and biodiesel without nanoparticles. In short, the nanoparticles in the biodiesel blend appear to have a beneficial effect in further reducing engine noise, particularly on the left side of the engine.

Figure 5: Sound pressure level at left position



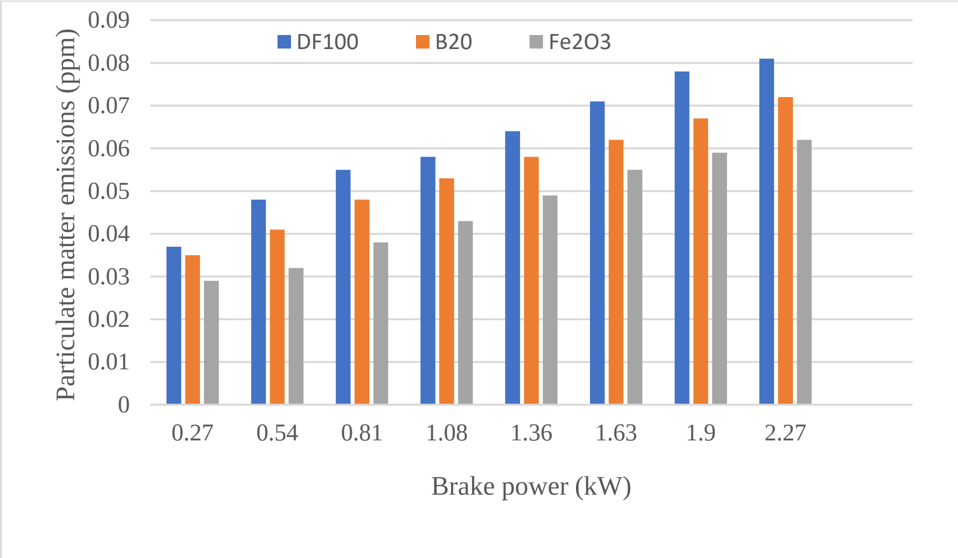
3.2. Particulate Matter (PM) emissions

PM emissions refer to the small solid particles and liquid droplets released into the air during engine combustion. These particles, including soot, ash, and other fine materials, can harm human health and the environment. PM is a significant pollutant in the context of diesel engines, often associated with incomplete fuel combustion. Biodiesel and additives like iron oxide can help reduce these emissions by promoting more complete combustion, thus decreasing the formation of particulates (Singh *et al.*, 2023)

Figure 6 demonstrates that using biodiesel results in a 3.859% reduction in particulate matter emissions compared to standard diesel fuel. Furthermore, when iron oxide is added to the biodiesel-blended fuel, particulate matter emissions are reduced even further, achieving a 9.18% reduction compared to pure diesel. This significant improvement can be attributed to the catalytic effect of iron oxide, which enhances the combustion process and reduces the formation of particulate matter during fuel combustion (Bhangwar *et al.*, 2022).

The study highlights that using biodiesel blends, particularly those enhanced with nanoparticles, significantly reduces both noise and particulate matter (PM) emissions in CI engines compared to pure diesel (D100). Biodiesel's oxygen content promotes a more complete combustion process, resulting in lower noise levels, while the addition of nanoparticles further improves combustion efficiency, reduces mechanical friction, and lowers emissions. The findings demonstrate that nanoparticles, acting as combustion catalysts, can help dampen engine noise and reduce particulate matter emissions, especially in high-emission scenarios, contributing to better engine performance and environmental outcomes.

Figure 6: Particualte matter emissions



However, critical considerations remain, such as the long-term effects of nanoparticles on engine durability and maintenance, and potential environmental concerns related to nanoparticle production and post-combustion effects. While the results are promising for reducing pollution and meeting stricter emissions standards, further research is needed to fully understand the interactions of nanoparticles in combustion and to assess the economic feasibility of widespread adoption. Real-world applications and cost-benefit analyses will also be key in determining the viability of biodiesel with nanoparticles in broader industrial and transportation sectors.

4. Conclusion

The objectives of the research were to analyse the performance of a diesel engine (D.E) using biodiesel as an additive (by evaluating brake thermal efficiency), to assess engine noise emission levels, and to calculate carbon emission levels when using biodiesel additives D100 and B20 (derived from waste cooking oil) without any modifications to the engine. For this study, two samples were tested, and the engine was operated at 10-minute intervals to achieve the research objectives. A proper research methodology was organized accordingly. The study also analysed engine noise emission levels. The results indicated that noise emissions were lower when using the B20 blend compared to D100. This reduction in noise emissions could be attributed to the physical properties of the biodiesel and its increased oxygen content. Additionally, particulate matter emissions from the compression ignition engine were reduced when using nanoparticle-infused and biodiesel-blended fuel samples.

Declaration of conflict of interest

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