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Original Article

Enhancing Diesel Engine Performance and Emission Control Using Nanoparticles in Ethanol-Diesel Emulsions

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Abstract *- This study analyses a C.I. engine's performance and emission characteristics using ethanol-diesel emulsions containing $NiZnFe_2O_4$ nanoparticle* nanoparticles. *A four-stroke, single-cylinder, and diesel engine test rig was employed to evaluate different ethanol concentrations (5%, 10%, and 15%) and nanoparticle levels (25 ppm, 50 ppm, and 100 ppm) in the emulsions. The tests showed clear improvements in engine performance, fuel consumption, and emissions. The inclusion of $NiZnFe_2O_4$ NPs in ethanol-diesel emulsions significantly lowered BSFC due to the nanoparticles acting as catalysts that enhanced combustion efficiency by increasing heat release and cylinder pressure. Without the nanoparticles, BSFC for ethanol blends increased by 27.17%, 34.39%, and 37.87% for the E5, E10, and E15 samples, respectively, compared to diesel. However, when nanoparticles were added, fuel consumption was greatly reduced. In terms of emissions, the nanoparticles effectively reduced hydrocarbon (HC) and smoke emissions. HC emissions dropped by 50%, 58%, and 71%, while smoke opacity fell by 59%, 69%, and 61% for the E103N25, E103N50, and E103N100 fuel samples, respectively. These reductions were linked to improved combustion, facilitated by better atomization and fuel-air mixing due to the nanoparticles. However, carbon dioxide (CO_2) emissions increased slightly due to more complete combustion. The findings suggest that graphite oxide nanoparticles could serve as a complementary or alternative Nano-catalyst in ethanol-diesel blends, further enhancing combustion efficiency and reducing emissions. This research underscores the potential of nanotechnology, including graphite oxide dosing, in creating cleaner, more efficient diesel engines with significant environmental and economic benefits.*

Keywords *- Nickel zinc iron oxide, Graphite oxide dose, Ethanol-diesel emulsions, Compression ignition engine, Fuel consumption.*

1. Introduction

In modern times, the extensive utilization of fossil fuels in IC engines might result in the exhaustion of fossil fuel reserves. Fossil fuel burning generates noxious emissions that have the potential to alter the climate and compromise human health [1, 15]. Biodiesel fuel, derived from several sources, may be utilized as a replacement for deployment in diesel engines employing diesel fuel. Biodiesel is considered a green fuel due to its favorable combustion qualities, such as oxygenation and burning capacity [2, 3]. Biodiesel may be economically generated by the use of advanced technology, which can convert a range of resources, including animal fat, non-edible oil, and edible oil [4]. It is important to understand that raw oil derived from biodiesel sources cannot be utilised in diesel engines without being converted into biodiesel fuels. Raw oil has elevated viscosity, density, and water content [5]. Gum may build in the injection components and CC due to the higher viscosity of the gasoline. The presence of water may lead to corrosion and deterioration of the engine components [6]. Various manufacturing processes, including micro-emulsion, transesterification, dilution, and pyrolysis, may be used to manufacture biodiesel from WCO [7]. To accomplish dilution, it is possible to blend WCO with fossil diesel fuel, but the WCO should not exceed 20% of the whole mixture. Engine damage caused by WCO may be prevented by dilution [8]. Pyrolysis breaks down oil by heating without O2 [9]. A micro-emulsion is a kind of colloidal dispersion where fat is coupled with either methanol or ethanol as a solvent. This combination serves to decrease viscosity as well as enhance the quality of spraying [10]. Transesterification is a chemical process that transforms biodiesel resources into FAME and glycerol. This process involves the utilization of alcohol, such as methanol, as well as a catalyst. The catalysts may be classified into four categories: base, enzyme, nanocatalyst, and acid. Base catalysts have several advantages, including their widespread availability, lower energy demand [16], reduced corrosion risks for engine parts, and quicker reaction rates than acid catalysts [11].

In recent research, different concentrations of Cyclohexane, a flammable liquid, were added by volume to WCO biodiesel and diesel fuel in three blends: B60:D35C5, B60D30C10, and B60D25C15. The concentrations of Cyclohexane used were 5%, 10%, and 15%. The findings demonstrated that using fuel mixes resulted in enhanced engine effectiveness and emission properties compared to conventional fossil diesel fuel. Furthermore, the UHC, CO, and BSFC were reduced due to raising the IP from 150 bars to 250 bars. A comparative analysis was performed utilizing a diesel engine in an experimental investigation to assess the disparities between two combustion modes: mix, add fuel combustion, and RCCI combustion. The fuel mixture was a combination of biodiesel and n-butanol, with different rates of EGR, injection timings, and engine loads. The ideal EGR percentage was 30%. The mixed fuel mode achieved a high Brake Thermal Efficiency and lower emissions, but it resulted in elevated nitrogen oxides (NOx) [12]. Furthermore, recommendations for enhancing the combustion and emission properties using sophisticated technology were implemented in traditional diesel engines [13, 14]. The idea of the PPC engine was implemented using a fuel with a high-octane rating and oxygen content, such as methanol, along with various fuel injection techniques. Furthermore, the use of a low-carbon fuel like alcohol resulted in emissions savings of up to 10% under certain circumstances as compared to conventional engines.

This study caters to a diverse range of entities, including governments, organizations, and persons. Countries without significant petroleum reserves benefit from reducing their foreign currency expenditure on gasoline imports. Molasses is a residual substance derived from sugar manufacturing and is generated by sugar refineries. This secondary product is progressively used for the production of ethanol. Nevertheless, several sugar enterprises fail to use molasses effectively to generate ethanol. Using the byproduct for ethanol generation confers advantages to the sugar sector. Ethanol may also be produced from maize, sugar beets, and additional feedstocks for agriculture, making this study advantageous for agricultural enterprises and people. The increased ethanol production facilities will provide work opportunities for citizens, contributing to stabilising the public economy. The whole community reaps the advantages of less pollution resulting from the use of diesel engines.

1.1. Research Gap and Problem Statement

Despite the growing interest in ethanol-diesel emulsions as an alternative fuel, several critical challenges remain unresolved in improving their performance and emissions. While ethanol blends have demonstrated the potential to reduce certain emissions, they often increase BSFC and suboptimal CE, especially at higher ethanol concentrations. Furthermore, the impact of NPs on engine performance, particularly in terms of emission reduction and fuel efficiency improvement when used with ethanol-diesel emulsions, is not well understood. Nanotechnology has emerged as a promising tool to improve CE and reduce emissions in IC engines. Previous studies have shown that nanoparticles such as $NiZnFe_2O_4$ can enhance combustion by improving fuel atomization and increasing heat release. However, the specific effects of varying concentrations of $NiZnFe_2O_4$ nanoparticle nanoparticles in ethanol-diesel emulsions, especially concerning their impact on fuel consumption, emissions, and engine performance, are not fully explored. Moreover, while $NiZnFe_2O_4$ nanoparticles have shown promise, the potential of graphite oxide nanoparticles as an alternative or complementary catalyst remains largely unexplored. With its high surface area and unique catalytic properties, Graphite oxide could further enhance combustion efficiency, improve fuel-air mixing, and reduce emissions in ethanol-diesel blends. This study aims to fill these gaps by analyzing the impact of $NiZnFe_2O_4$ nanoparticles in ethanol-diesel emulsions, assessing their effects on BSFC, hydrocarbon emissions, smoke opacity, and overall engine performance. Additionally, it explores the potential for graphite oxide nanoparticles as an alternative or complementary catalyst in enhancing combustion efficiency and reducing harmful emissions, thereby aiding in creating more environmentally friendly and sustainable fuel blends.

1.2. Novelty of this Work

The novelty of this work lies in its dual approach to improving the performance and emissions of ethanol-diesel emulsions by incorporating nanoparticles and exploring the graphite oxide nanoparticles as a complementary catalyst. While previous studies have investigated the effects of various nanoparticles in diesel or biodiesel blends, there is a lack of research that systematically analyzes the combination of these nanoparticles in ethanol-diesel emulsions.

This study uniquely addresses this gap by:

- Investigating the combined effect of $NiZnFe_2O_4$ nanoparticles at varying concentrations (25 ppm, 50 ppm, 100 ppm) on engine performance and emission characteristics when used with different ethanol concentrations (5%, 10%, 15%).
- Exploring graphite oxide nanoparticles as an alternative or supplementary catalyst to $NiZnFe_2O_4$ nanoparticles, a relatively unexplored area in the context of ethanol-diesel emulsions. Graphite oxide's potential to enhance CE and reduce harmful emissions makes it a promising avenue for future fuel formulations.
- Providing a comparative analysis of nanoparticle-enhanced ethanol-diesel emulsions paving the way for future research and practical applications that aim for cleaner, more efficient IC engines.

This novel approach advances the understanding of nanotechnology's role in improving ethanol-diesel emulsions and opens new possibilities for sustainable and eco-friendly fuel options in automotive and industrial applications.

2. Review of Literature

Bayindirli et al. (2024) [17] conducted an experimental investigation to explore the potential benefits of reduced graphene oxide (GO) in enhancing fuel performance and reducing engine emissions. The study emphasized GO's high surface area, reactivity, and excellent conductivity, contributing to its effectiveness as a fuel additive. Outcomes showed that the BTE significantly improved with nanoparticle (NP) additives, highlighting a direct relationship between the concentration of NPs and heat release rates. The study also reported that ID and CD were reduced by approximately 2% to 5.09% and 0.84% to 5.85%, respectively, when using CGt-75 as well as CGn-75 fuels compared to conventional C0 fuels. These reductions, combined with improved thermophysical properties and heat transfer rates, led to substantial improvements in hydrocarbon (HC) emissions, achieving reductions of 8.98%, 11.79%, 14.04%, and 15.73%, respectively, with increasing nanoparticle concentrations.

Pullagura et al. (2024)[18] focused on the development of sustainable energy solutions by incorporating graphene NPs (G) along with n-Butanol into sterculia foetida biodiesel-diesel blends to increase engine efficiency and decrease emission. In this investigation, 50 mg/L of graphene NPs, as well as 10% n-Butanol, were added to biodiesel-diesel blends, while hydrogen (H2) was supplied as a secondary fuel at flow rates of 3 and 6 liters per minute. Compared to B20 (a 20% biodiesel blend), the study found that higher loads reduced CO emissions by 19.75%, HC by 24.86%, and smoke opacity by 9.58%. The results suggest that these additives and hydrogen supply could provide substantial performance and emission improvements for stationary engines used in various industrial sectors.

Sule et al. (2024) [19] examined the effects of ethanol and butanol, combined with magnetite nanoparticles (100 ppm), on the performance of biofuels. A blend of 10% ethanol and butanol (equally mixed with magnetite NPs) and 90% palm oil biodiesel (B100) was tested on a Yanmar L70N engine. Findings demonstrated that including magnetite NPs reduced the BSFC by 15.68%, from 10.4 gm/kW-hr (for pure B100) to 8.8 gm/kW-hr at MBP. The improvement in fuel efficiency was accompanied by enhanced combustion performance, suggesting that hybrid biofuels with nanoparticle additives could be a promising approach to improving biodiesel engine performance.

Siddiqui et al. (2023) [20] carried out an experimental analysis on the effects of Fe2O3 and graphite (G) nanoparticles as fuel additives in petrol, with concentrations of 40, 80, and 120 mg/L. The tests were conducted on an air-cooled 1C4S petrol engine, and the results indicated that G-blended fuels significantly improved torque, BTE, and brake power while reducing BSFC compared to Fe2O3-blended fuels. The study highlighted the advantages of nonmetallic fuel additives like graphite, which offer improved fuel performance without the environmental risks associated with metallic additives.

Rajak et al. (2023)[21] explored the effects of varying concentrations of ZnO nanoparticles (0.025%, 0.05%, and 0.1%) in diesel fuel on engine effectiveness, emissions, combustion, along with injection properties. Under full load conditions, the engine had been evaluated at speeds between 2000 and 3000 rpm. The findings demonstrated that the addition of 0.1% ZnO led to an 11.7% increase in BTE at 2500 rpm, along with a 1.67% reduction in Specific Fuel Consumption (SFC), an 11.4% decrease in exhaust gas temperature, and a 10.67% reduction in NOx emissions. Furthermore, the addition of ZnO NPs raised the pressure of the cylinder by 2.3%, indicating a positive impact on combustion efficiency.

Billa et al. (2022) [22] employed a Full Factorial Design-based RSM to optimize the engine intakes for a diesel engine running on biodiesel/diesel/n-Octanol blends with nano-GO additives. The study determined that an optimal blend of 3.898% n-Octanol and 49.772 ppm nanoGO at a load of 99.2% achieved a desirability index of 0.997. The optimal blend resulted in reductions of 15.6% in CO emissions, 21.78% in unburned hydrocarbons (HC), and 3.26% in NOx emissions compared to petrodiesel while enhancing engine efficiency.

Agbulut et al. (2022)[23] focused on using GO NPs in combination with WCO methyl ester and diesel fuel blends to evaluate their effects on a diesel engine's efficiency, combustion, and emissions. Test fuels included B0 (pure diesel), B15 (85% diesel, 15% WCO), and B15 with various concentrations of GO (100, 500, and 1000 ppm). According to the findings, GO decreased BTE by 2.67%, CO emissions by 7.5%, HC emissions by 8.53%, and BSFC by 5.54% when added to biodiesel blends. Additionally, NOx emissions were reduced by 3.37%, indicating that GO nanoparticles can improve biodiesel blends' combustion properties and emissions profile.

Gad et al. (2021) [24] investigated how alumina NPs affected diesel engine performance, emissions, and combustion properties. Alumina NPs were added to crude diesel at 20, 30, and 40 mg/L concentrations. The results demonstrated that including 40 ppm alumina nanoparticles led to a 5.5% rise in TE compared to pure diesel. At full load, specific fuel consumption decreased by 3.5%, 4.5%, and 5.5% at alumina concentrations of 20, 30, and 40 ppm, respectively. The nanoparticles improved fuel stability and atomization, improving combustion efficiency and reducing fuel injector clogging.

Jayaraman et al. (2021) [25] studied the effects of IP and GO NPs on a diesel engine running on biodiesel derived from Sapota seeds. Blends of 10% and 20% Sapota Seed Oil with diesel were tested with 50 ppm GO nanoparticles, and the engine was operated at injection pressures of 200 and 220 bar. Investigations revealed that adding GO NPs to the blends lowered CO and HC emissions, with B20GO50 producing the lowest emissions. The study emphasized the importance of optimizing injection pressure to maximize the benefits of NP additives in biodiesel blends. Hoseini et al. (2020) [26] investigated the impact of GO NPs on the effectiveness and emissions of a diesel engine using biodiesel derived from Oenothera lamarckiana. The B20 biodiesel blend was tested with GO nanoparticle concentrations of 30, 60, and 90 ppm at several load conditions (0% to 100%) and the same speed of 2100 rpm. The findings revealed that using GO nanoparticles significantly enhanced engine power and Exhaust Gas Temperature (EGT) while improving emission characteristics such as NOx, CO, CO2, and Unburned Hydrocarbons (UHCs). The study concluded that GO nanoparticles could significantly improve biodiesel fuel efficiency and environmental performance.

3. Methodology

3.1. Experimental Design Overview

The current study aims to analyze the effectiveness and emission properties of a CI engine fueled by ethanol-diesel emulsions with the addition of $NiZnFe_2O_4$ nanoparticle NPs and graphite oxide nanoparticles. Both types of nanoparticles are incorporated into the emulsions to evaluate their individual and comparative effects on engine performance and emissions. The emulsions are stabilized using Tween 80 and Span 80, which form an emulsifying agent with an HLB of 9. The study investigates the effect of nanoparticle concentrations (25, 50, and 100 ppm) on engine performance and emissions, with a focus on both types of nanoparticles.

3.2. Materials and Sample Preparation

3.2.1. Fuel Mixture

The fuels are prepared by emulsifying ethanol (aqueous solution with 3% water) in diesel fuel. The ethanol content varies in three ratios (5%, 10%, and 15% by volume).

3.2.2. Emulsifiers

Tween 80 and Span 80 are used in a ratio calculated to achieve an HLB value of 9, which is necessary for the stability of the ethanol-diesel emulsion.

$$HLB\ of\ emulsifier\ mixture = \frac{Mass\ span\ 80 \times HLB\ span\ 80 + mass\ tween\ 80 \times HLB\ Tween\ 80}{Mass\ tween\ 80 + mass\ span\ 80}$$

$$mass\%\ tween\ 8 = \frac{HLB\ of\ mixture - HLB\ of\ span\ 80}{HLB\ of\ tween\ 80 - HLB\ of\ span\ 80}$$

$$mass\%tween80 = \frac{9 - 4.3}{15 - 4.3} = 44\%$$

$$mass\%span80 = 100 - 40 = 66\%$$

The mass percentages are 44% Tween 80 and 66% Span 80.

3.2.3. Nanoparticles and Surfactants

$NiZnFe_2O_4$ nanoparticle nanoparticles are added to the emulsions at three concentrations (25, 50, and 100 ppm). CTAB is added as a surfactant in equal mass quantities to prevent sedimentation.

3.3. Fuel Emulsion Preparation

The emulsification process consists of two key steps:

3.3.1. Stage 1 (Sonication)

Emulsifiers (Tween 80 and Span 80) are mixed using an ultrasonicator at 25°C and 40 kHz for 30 minutes.

3.3.2. Stage 2 (Magnetic Stirring)

Diesel, ethanol, and emulsifier are stirred at 25°C and 1400 rpm for 20 minutes.

3.3.3. Stage 3 (Magnetic Stirring with Nanoparticle Addition)

Nanoparticles and surfactant (CTAB) are inserted into the emulsion, and ten more minutes are spent stirring the mixture. The mixture undergoes additional magnetic stirring at 25°C and 1400 rpm.

3.3.4. Stage 4 (Final Sonication)

Finally, the emulsion with the nanoparticles and surfactant is subjected to another ultrasonic treatment at 25°C and 40 kHz for 30 minutes to ensure complete dispersion and stability of the fuel mixture.

3.4. Fuel Sample Stability Testing

The stability of five fuel samples (D95E5, D90E10, D85E15, D90E103N50, and D90E103N100) is assessed at room temperature (20°C - 30°C) over a specific period. The emulsion is visually monitored for phase separation and any signs of instability.

3.4.1. Composition and Stability of Fuel Samples

Below samples were prepared to assess their stability and performance in diesel engine testing-

- D95E5: The mixture consists of 95% diesel and 5% ethanol. Tween 80 (HLB: 15) and Span 80 (HLB: 4.3) are utilized as emulsifiers for stability.
- D90E10: This sample contains 90% diesel and 10% ethanol, with 44% of the emulsifying solution made up of Tween, which helps maintain a stable emulsion.
- D85E15: Comprising 85% diesel and 15% ethanol, this fuel sample uses 56% Span as the emulsifier for stability.
- D90E103N50: Contains 90% diesel, 10% ethanol, and 50 ppm of Nickel Zinc Iron Oxide nanoparticles (NP), with Cetyl Trimethyl Ammonium Bromide (CTAB) added as a surfactant to enhance nanoparticle dispersion.
- D90E10 3N100: This mixture includes 90% diesel, 10% ethanol, and 100 ppm of $NiZnFe_2O_4$ nanoparticles, stabilized with the help of CTAB as a surfactant.

3.5. Performance Evaluation

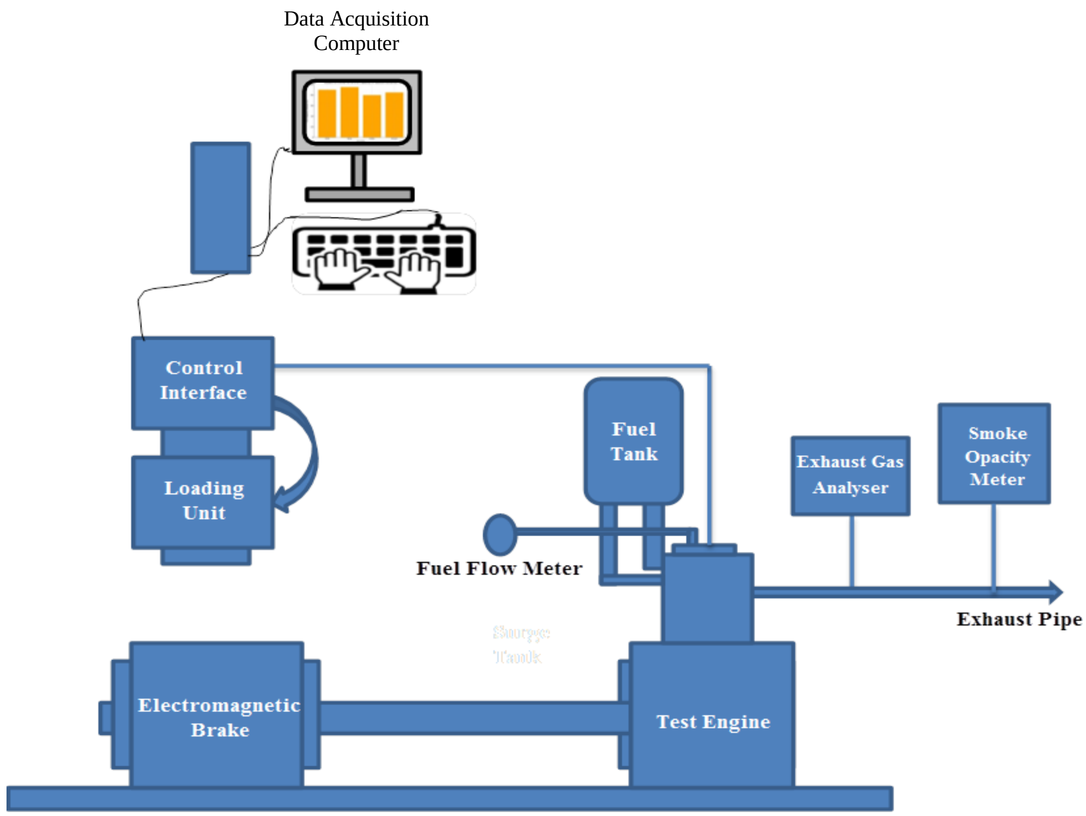

Fig. 1 Overview of the performance and emission testing setup

3.5.1. Test Rig Setup

The 1C4S CI engine is coupled with an ECD to evaluate performance parameters. The engine load varies, and a data acquisition system records fuel consumption, power output, and torque.

3.5.2. Performance Parameters

- **Engine Load:** The engine operates at various loads ranging from 0% to 100% of full load.
- **Fuel Consumption (FC):** The rate of FC (L/h) is measured.
- **Power and Torque:** Recorded at different loads for each fuel sample.

3.6. Emission Analysis

3.6.1. Exhaust Gas Measurement

The exhaust gases (CO, CO_2, O_2, HC, NOx) are measured using an exhaust gas analyzer. Calibration is done by introducing fresh air into the sensors, setting CO_2 and O_2 reference values to 0 and 20.9%, respectively.

3.6.2. Opacity Measurement

The SO is measured using an opacimeter or smoke meter. After calibration, the smoke density (opacity) is recorded in percentage (0-99.90%).

3.7. Testing Procedure

3.7.1. Engine Operation

The engine is operated at varying loads, and data are collected in three replicates for accuracy.

3.7.2. Emission Monitoring

CO, CO_2, HC, O_2, and NOx are monitored after each load change, with a settling time of 1 minute before each measurement.

3.7.3. Smoke Measurement

The opacity of the exhaust smoke is measured simultaneously to assess soot emissions.

3.8. Data Analysis

- The experimental data on fuel consumption, power, torque, and emissions are analyzed. Trends are identified, and comparisons are made between the different fuel samples.

- Emission parameters like HC and NOx are compared for the three nanoparticle concentrations, while performance parameters like fuel consumption and torque are compared with the baseline diesel-ethanol samples.

The methodology provides a comprehensive framework for assessing the effects of mixes of ethanol and diesel with $NiZnFe_2O_4$ nanoparticle nanoparticles on the effectiveness and emissions of a C.I. engine. The tests are designed to measure combustion efficiency improvements, emissions reductions, and engine performance enhancement.

4. Experimental Investigation and Modelling of C.I. Engine with Graphite Oxide Dose as Nanoparticle in Ethanol-Diesel Blends

This section describes how the study's experimental approach and modelling framework will help achieve the objectives outlined in the title: Experimental Investigation and Modelling of C. I Engine with Graphite Oxide Dose as Nanoparticle in Ethanol-Diesel Blends. The key objectives of the study are to:

4.1. Identify the Engine's Performance Parameters with Increasing Concentrations of Graphite Oxide Nanoparticles

The engine performance will be evaluated by measuring power output, torque, and fuel consumption under varying engine loads. The effect of nanoparticle concentration on engine performance can be assessed by testing multiple ethanol-diesel blends with increasing concentrations of graphite oxide NPs (25, 50, and 100 ppm). The nanoparticles' catalytic role is expected to enhance CE, reduce fuel consumption, and improve overall engine output. The correlation between the nanoparticle dose and engine performance will be modeled to predict improvements at different concentrations.

4.2. Identify the Emission Parameters of the Engine with Increasing Concentrations of Graphite Oxide Nanoparticles

The study will also focus on emission reduction, a significant environmental benefit. The influence of increasing NP concentrations on emissions will be quantified by analyzing exhaust gases such as CO, CO_2, HC, NOx, and SO. The role of graphite oxide NPs in improving combustion efficiency is expected to reduce harmful emissions, including unburned hydrocarbons and particulate matter, while potentially increasing CO_2 emissions due to more complete combustion. Emission trends will be modeled to understand the nanoparticle's effectiveness at different doses.

4.3. Identify the Specific Fuel Consumption (SFC) with Increasing Concentrations of Graphite Oxide Nanoparticles

One of the critical performance indicators is **SFC**, which measures the engine's fuel efficiency. The effect of these additives on fuel consumption can be determined by testing ethanol-diesel emulsions with varying concentrations of graphite oxide NPs. The study aims to identify optimal nanoparticle concentrations that result in the lowest SFC while maintaining engine performance and reducing emissions. The relationship between nanoparticle concentration and SFC will be modeled to provide insights into the most fuel-efficient formulations.

Through a combination of experimental testing and modelling, this study will explore the interplay between nanoparticle concentration, engine performance, emissions, and fuel consumption. By achieving these objectives, the study will provide valuable data on how graphite oxide NPs can be applied to improve the efficiency of ethanol-diesel blends, offering potential solutions for cleaner and more efficient CI engines.

5. Results and Discussion

It concentrates on the impact of ethanol as well as $NiZnFe_2O_4$ nanoparticles on the efficiency and emission properties of a diesel engine using ethanol-diesel emulsions. Key parameters such as CO_2 emissions, HC, fuel consumption, and smoke opacity were examined under different engine load conditions.

5.1. Fuel Consumption (FC)

The impact of ethanol on BSFC under various load conditions is shown in Figure 2. At minimal load, BSFC is initially lower because less fuel is needed. As the engine load rises to 50%, BSFC increases due to the need for more fuel to meet power demand. However, at higher loads (up to 80%), BSFC decreases, indicating improved engine efficiency at heavier loads. Figure 3 shows the Impact of $NiZnFe_2O_4$ nanoparticles on the E10 emulsion. FC decreased by 16.79%, 27.86%, and 27.48% for E103N25, E103N50, and E103N100 formulations, respectively, compared to E10 without nanoparticles. This reduction is due to the catalytic role of the nanoparticles, which enhance combustion by increasing temperature, cylinder pressure, and heat release rate, resulting in lower fuel consumption and increased engine power.

5.2. Hydrocarbon Emissions

As shown in Figure 4, HC emissions raised with higher engine loads. As an oxygenated fuel, ethanol enhances combustion, which usually results in lower HC emissions. However, ethanol in the fuel mixture raised HC emissions by 78% compared to pure diesel, mainly due to ethanol's lower CN, which can lead to incomplete combustion. With NiZnFe2O4 nanoparticles in the E10 emulsion, HC emissions were significantly reduced. The nanoparticles' catalytic properties promote more complete combustion, leading to a decrease in HC emissions.

5.3. Carbon Dioxide Emissions

Figure 5 shows the relationship between CO_2 emissions and engine load. Ethanol use in diesel fuel increased CO_2 emissions, as ethanol contains more oxygen and promotes CO_2 formation during combustion. The addition of $NiZnFe_2O_4$ nanoparticles further increased CO_2 emissions due to more complete combustion. The average CO2 emissions for E10, E0, E103N25, E103N50, and E103N100 formulations were higher compared to pure diesel, with increases of 9%, 14%, 16%, and 19%, respectively.

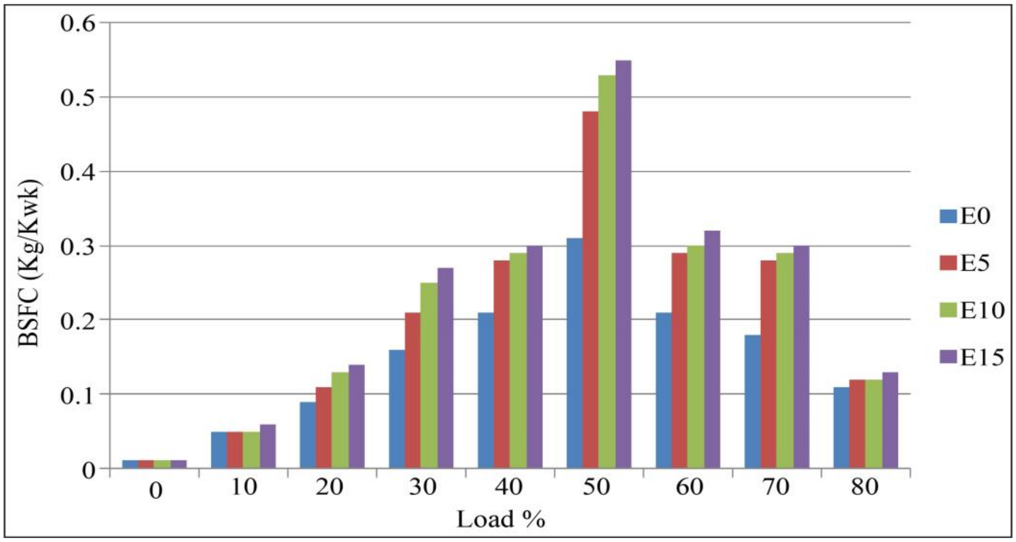

Fig. 2 Impact of Ethanol blends on BSFC across varying loads

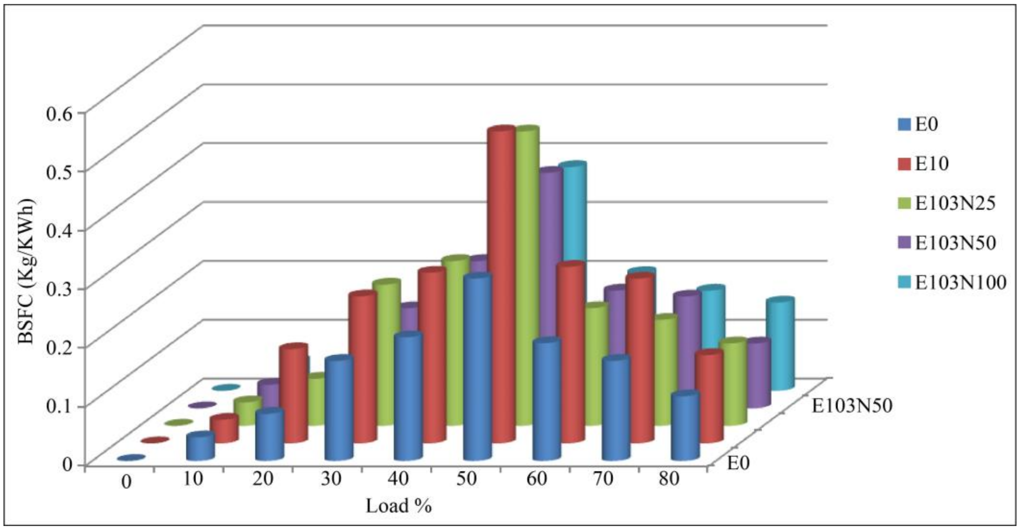

Fig. 3 Impact of NiZnFe2O4 on fuel consumption for E10 blends across varying engine loads

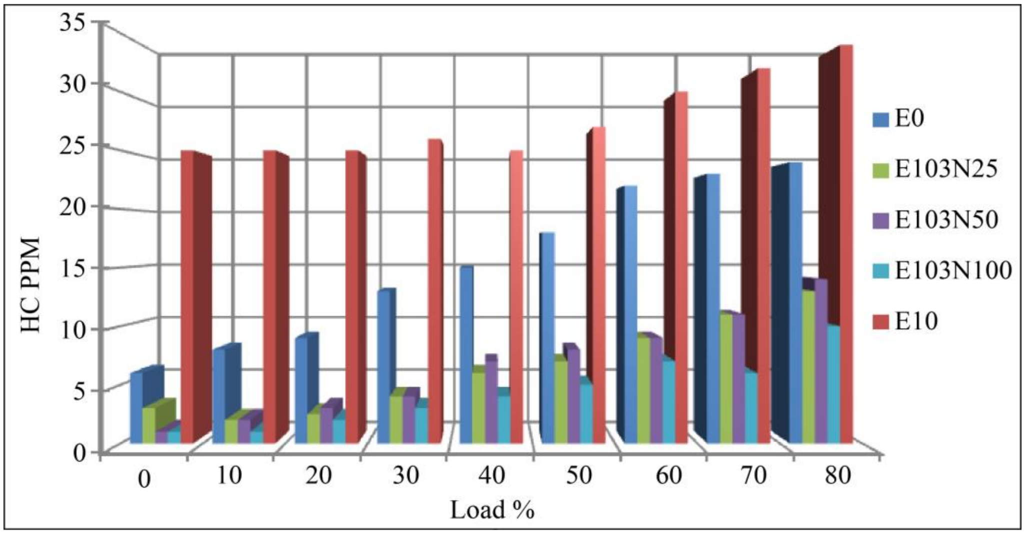

Fig. 4 Influence of NiZnFe2O4 nanoparticles on HC emission levels in E10

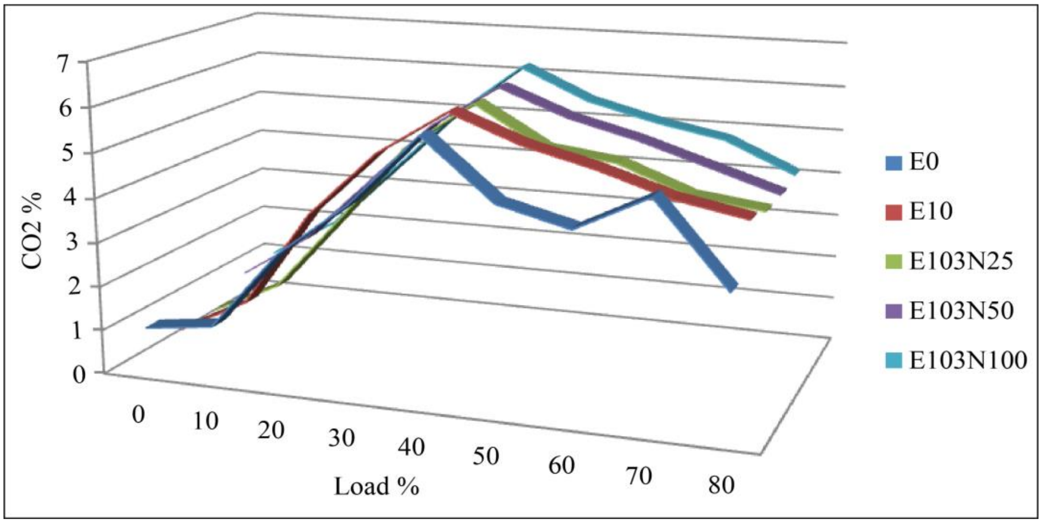

Fig. 5 Influence of NiZnFe2O4 nanoparticles on CO2 emission levels in E10

5.4. Smoke Opacity (SO)

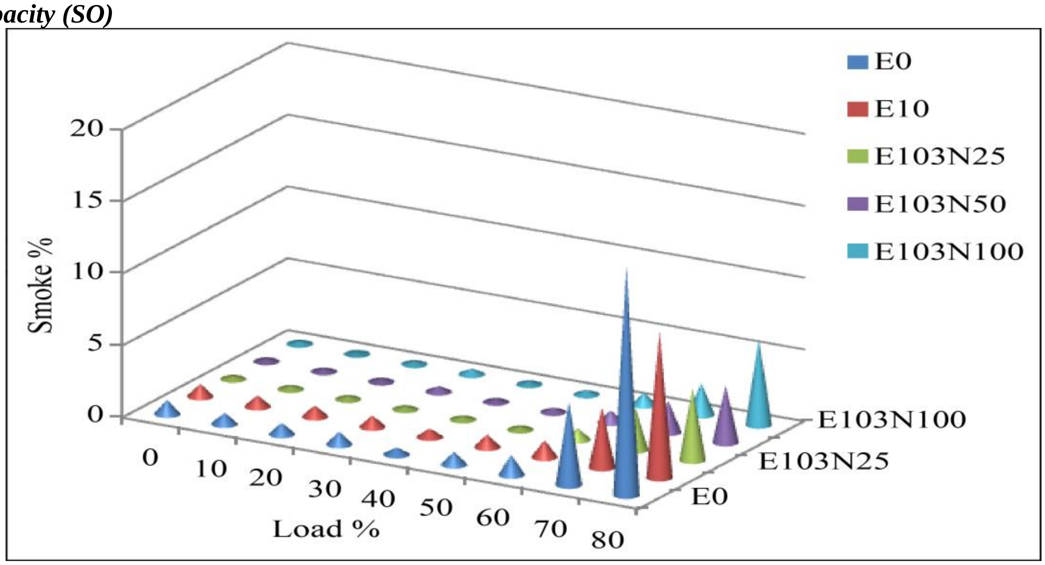

Fig. 6 Influence of NiZnFe2O4 nanoparticles on smoke emission levels in E10

Figure 6 illustrates the effect of ethanol and nanoparticles on SO. The ethanol-diesel emulsion led to lower smoke emissions than pure diesel, particularly at higher loads, due to ethanol's better combustion properties. Adding $NiZnFe_2O_4$ nanoparticles further reduced smoke emissions. At loads above 60%, smoke emissions were reduced by 60%, 69%, and 61% for E103N25, E103N50, and E103N100, respectively. The nanoparticles help improve combustion efficiency, leading to lower particulate matter and smoke in the exhaust. Adding ethanol to emulsions for diesel fuel, along with NiZnFe2O4 nanoparticles, significantly affected the engine's effectiveness and emission properties. Fuel consumption was dropped, hydrocarbon and smoke emissions were lowered, and combustion efficiency was improved, leading to larger CO2 emissions due to complete combustion. These findings suggest that ethanol-diesel emulsions with nanoparticle additives could be a promising alternative for lowering emissions and improving engine efficiency in diesel engines.

6. Conclusion

This work explores the influence of $NiZnFe_2O_4$ nanoparticle nanoparticles in ethanol-diesel emulsified fuel on the effectiveness and emission properties of a C.I. engine. The tests were conducted on a 1C4S diesel engine test setup, blending ethanol and nanoparticles in different concentrations to achieve a homogeneous solution. The results show significant emissions, fuel consumption, and engine performance improvements.

Key findings include:

6.1. BSFC

Compared to pure diesel, ethanol-diesel emulsions showed higher BSFC, with E5 fuel exhibiting a 27.17% increase, E10 showing a 34.39% increase, and E15 showing the highest increase of 37.87%. However, adding nanoparticles reduced fuel consumption because of their catalytic activity, which increased burning efficiency.

6.2. Hydrocarbon Emissions (HC)

The presence of $NiZnFe_2O_4$ nanoparticles caused a noticeable drop in HC emissions, with reductions of 50% for E103N25, 58% for E103N50, and 71% for E103N100 fuel samples. This shows that nanoparticles are important in boosting the burning process, leading to fewer unburned hydrocarbons in the exhaust.

6.3. Smoke Emissions

Compared to pure diesel, ethanol-diesel emulsions decreased the opacity of smoke. Including nanoparticles further reduced smoke emissions, with reductions of 59% for E103N25, 69% for E103N50, and 61% for E103N100. The largest reduction in emissions of smoke was achieved with the E103N50 sample, showing a 69% decrease.

6.4. Role of Nanotechnology in Engine Performance

These findings highlight the potential of nanotechnology, particularly $NiZnFe_2O_4$ nanoparticles, in improving engine performance and reducing emissions. The results align with previous studies suggesting nanoparticles can enhance combustion efficiency and reduce environmental impacts. Additionally, The paper emphasises the possible contribution of Graphite Oxide Dose as a Nanoparticle in ethanol-diesel blends. Graphite oxide nanoparticles, known for their catalytic properties and high surface area, could further improve fuel-air mixing, combustion efficiency, and emission reductions. Future studies incorporating graphite oxide in combination with other nanoparticles could yield even greater performance and environmental benefits.

Future Research Directions:

- Scaling Up the Process: Conducting extensive field trials on larger engines and real-world vehicles to validate the scalability of these findings.
- Exploring Other Nanoparticle Combinations: Investigating the combined effects of $NiZnFe_2O_4$ and graphite oxide nanoparticles to achieve optimal performance and emission reductions.
- Optimizing Concentrations: Examining various doses of graphite oxide and other nanoparticles to find the most efficient ratios for enhanced combustion and lower emissions.
- Comprehensive Environmental Impact Studies: Evaluating the long-term financial and environmental advantages of using ethanol-diesel mixtures enhanced with nanoparticles.

In conclusion, the study demonstrates that blending ethanol-diesel emulsions with $NiZnFe_2O_4$ nanoparticle nanoparticles and potentially graphite oxide nanoparticles can dramatically improve engine efficiency and reduce hazardous emissions. These advanced fuel formulations hold promising applications for developing more eco-friendly and fuel-efficient engines, providing significant benefits for the automotive and energy industries.

Abbreviation

Acronym	Full Form
SFC	Specific Fuel Consumption
EGR	Exhaust Gas Recirculation
HT	Heat Transfer
C.I	Compression Ignition
CO	Carbon Monoxide
SFC	Specific Fuel Consumption
UHCs	Unburned Hydrocarbons
1C4S	Single-cylinder, Four-stroke
ZnO	Zinc Oxide
BTE	Brake Thermal Efficiency
EDC	Eddy Current Dynamometer
BSFC	Brake-specific Fuel Consumption
NPs	Nanoparticles
Fe2O3	Metallic Iron Oxide
HC	Hydrocarbon
IC	Internal Combustion
ID	Ignition Delay
WCO	Waste Cooking Oil
NOx	Nitrogen Oxides
FAME	Fatty Acid Methyl Ester
RSM	Response Surface Method
GO	Graphene Oxide
IP	Injection Pressures

FIP	Fuel Injection Pressures
EGT	Exhaust Gas Temperature
HLB	Hydrophilic-Lipophilic Balance
$NiZnFe_2O_4$	Nickel Zinc Iron Oxide
CE	Combustion Efficiency
DES	Design-Expert Software
CD	Combustion Duration
MBP	Maximum Brake Power
CC	Combustion Chamber
TE	Thermal Efficiency
CN	Cetane Number
SO	Smoke Opacity

References

[1] P. Kumaran, A. Joel Godwin, and S. Amirthaganesan, "Effect of Microwave Synthesized Hydroxyapatite Nanorods Using Hibiscus Rosa-Sinensis Added Waste Cooking Oil (WCO) Methyl Ester Biodiesel Blends on The Performance Characteristics and Emission of a Diesel Engine," *Materials Today: Proceedings*, vol. 22, pp. 1047-1053, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[2] Akshey Marwaha et al., "Waste Materials as Potential Catalysts for Biodiesel Production: Current State and Future Scope," *Fuel processing technology*, vol. 181, pp. 175-186, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[3] Nikolaos Dimitrakopoulos et al., "PPC Operation with Low Ron Gasoline Fuel. A Study on Load Range on A Euro 6 Light Duty Diesel Engine," *In the Proceedings of the International symposium on diagnostics and modeling of combustion in internal combustion engines 2017.9, The Japan Society of Mechanical Engineers*, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[4] Medhat Elkelawy et al., "Influence of Lean Premixed Ratio of PCCI-DI Engine Fueled by Diesel/Biodiesel Blends on Combustion, Performance, And Emission Attributes; A Comparison Study," *Energy Conversion and Management: X*, vol. 10, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] Zhipeng Li et al., "Investigation of Effect of Nozzle Numbers on Diesel Engine Performance Operated at Plateau Environment," *Sustainability*, vol. 15, no. 11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Carlos Daniel Mandolesi de Araújo et al., "Biodiesel Production from Used Cooking Oil: A Review," *Renewable and sustainable energy reviews*, vol. 27, pp. 445-452, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[7] Digambar Singh et al., "A Comprehensive Review of Biodiesel Production from Waste Cooking Oil and Its Use as Fuel in Compression Ignition Engines: 3rd Generation Cleaner Feedstock," *Journal of Cleaner Production*, vol. 307, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[8] Emilia Paone, and Antonio Tursi, "Production of Biodiesel from Biomass," *Advances in Bioenergy and Microfluidic Applications*, pp. 165-192, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] Siddharth Jain, and M. P. Sharma. "Prospects of Biodiesel from Jatropha in India: A Review," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 2, pp. 763-771, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[10] May Ying Koh, and Tinia Idaty Mohd Ghazi, "A Review of Biodiesel Production from Jatropha Curcas L. Oil," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5, pp. 2240-2251, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[11] Haris Mahmood Khan et al., "Current Scenario and Potential of Biodiesel Production from Waste Cooking Oil in Pakistan: An Overview," *Chinese Journal of Chemical Engineering*, vol. 27, no. 10, pp. 2238-2250, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[12] Zunqing Zheng et al., "Experimental Study on Combustion and Emissions of N-Butanol/Biodiesel Under Both Blended Fuel Mode and Dual Fuel Rcci Mode," *Fuel*, vol. 226, pp. 240-251, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[13] Erik Svensson, Martin Tuner, and Sebastian Verhelst, "Influence of Injection Strategies on Engine Efficiency for A Methanol PPC Engine," *SAE International Journal of Advances and Current Practices in Mobility*, vol. 2, no. 2, pp. 653-671, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[14] Rohit P. Sarode, and Shilpa M. Vinchurkar, "An Approach to Recovering Heat from The Compressed Air System Based on Waste Heat Recovery: A Review," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 45, no. 3, pp. 9465-9484, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] Sarode, Rohit P, Vinchurkar, Shilpa M, and Gagan Malik, "Towards Sustainable Energy Practices: Experimental Assessment of Waste Heat Recovery from Multistage Air Compressor Operations," *Journal of Electrical Systems*, vol. 20, no. 7s, pp. 2735-2739, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[16] Rohit P. Sarode, Shilpa M. Vinchurkar, and Gagan Malik, "Advancements in Waste Heat Recovery from Multistage Air Compressor Operations," *Journal of Polymer and Composites*, vol. 13, no. 1, pp. 29-38, 2024. [Publisher Link]

[17] Cihan Bayindirli, Mehmet Celik, and Recep Zan, "Optimizing The Thermophysical Properties and Combustion Performance of Biodiesel by Graphite and Reduced Graphene Oxide Nanoparticle Fuel Additive," *Engineering Science and Technology, an International Journal*, vol. 37, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[18] Gandhi Pullagura et al., "Enhancing Performance Characteristics of Biodiesel-Alcohol/Diesel Blends with Hydrogen and Graphene Nanoplatelets in a Diesel Engine," *International Journal of Hydrogen Energy*, vol. 50, pp. 1020-1034, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[19] Ahmed Sule et al., "Effects of a Hybrid Additive of Ethanol-Butanol and Magnetite Nanoparticles on Emissions and Performance of Diesel Engines Fueled with Diesel-Biodiesel Blends," *International Journal of Automotive and Mechanical Engineering*, vol. 21, no. 2, 11350-11360, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[20] Yasir Hussain Siddiqui et al., "Enhancement of Combustion Effect Leading to Improved Performance and Exhaust Emissions of an SI Engine with Ferrous Oxide and Graphite Nanoparticles," *Environmental Science and Pollution Research*, 1-27, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Upendra Rajak et al., "Modifying Diesel Fuel with Nanoparticles of Zinc Oxide to Investigate its Influences on Engine Behaviors," *Fuel*, vol. 345, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[22] Kiran Kumar Billa et al., "Experimental Investigation on Dispersing Graphene-Oxide in Biodiesel/Diesel/Higher Alcohol Blends on Diesel Engine Using Response Surface Methodology," *Environmental Technology*, vol. 43, no. 20, pp. 3131-3148, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] Ümit Ağbulut et al., "Synthesis of Graphene Oxide Nanoparticles and the Influences of their Usage as Fuel Additives on CI Engine Behaviors," *Energy*, vol. 244, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[24] Mohammed S Gad et al., "Experimental Investigations on Diesel Engine Using Alumina Nanoparticle Fuel Additive," *Advances in Mechanical Engineering*, vol. 13, no. 2, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Yugandharsai et al., "Effects of Injection Pressure on Performance & Emission Characteristics of CI Engine Using Graphene Oxide Additive in Bio-Diesel Blend," *Materials Today: Proceedings*, vol. 44, pp. 3716-3722, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[26] S.S. Hoseini et al., "Performance and Emission Characteristics of a CI Engine Using Graphene Oxide (GO) Nano-Particles Additives in Biodiesel-Diesel Blends," *Renewable Energy*, vol. 145, pp. 458-465, 2020. [CrossRef] [Google Scholar] [Publisher Link]