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Studies on the Effect of the Zinc Oxide Nano Additives along with Rice Bran Biodiesel Diesel Blends into CI Engine to Reduce Pollution

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ABSTRACT

Pollution is a major problem for urban cities and their associated industries. The pollution caused by industries is mainly because of the burning of fossil fuels. Some of the pollutants can be controlled by plantation, but the oxides of nitrogen cannot be controlled only by planting trees. Some extra efforts are required to minimize pollution associated with the normal functioning of the shop floor of the industries concerned but not affecting its performance. The fuel that is best for industrial use is the need of the hour. In this study, zinc oxide nanoparticles are used as an additive to the rice bran blended biodiesel and analyze the combustion, performance, and emission parameters in the single-cylinder four-stroke engine water-cooled powered by diesel normally utilized in industries at a constant speed and compression ratio. The available fuel alternatives for testing consist of multiple combinations of diesel fuel and RB biodiesel, each with varying proportions. Furthermore, many gasoline mixes additionally have Zinc Oxide nanoparticles at a concentration of 30 parts per million (ppm). The findings suggest that the brake-specific fuel consumption of Rice bran biodiesel combined with Zinc oxide nano additive exhibits a consistent enhancement, but the brake thermal efficiency declines in comparison to diesel fuel. The concentrations of hydrocarbon (HC) and oxides of nitrogen (NO_X) have been reduced. However, there has been a small rise in carbon dioxide (CO_2) and carbon monoxide (CO). When rice bran biodiesel fuel combined with Zinc Oxide nano additive was used, an abnormally high exhaust gas temperature (EGT) was detected. According to this research, the addition of Zinc Oxide nano additive to rice bran biodiesel blends improves performance and decreases the noxious exhaust emissions generated by diesel engines.

INTRODUCTION

Rapidly increasing pollution in the urban cities of popular countries is harmful to human health. Most of the polluted content raised by diesel engine-driven industries is inevitable, and reducing these toxic elements from the atmosphere becomes impossible. The use of fossil fuels in industries is responsible for greenhouse gases and affects human health directly. Due to the unexpected rise in harmful toxicities, numerous alternative fuels have been taken for compensation in place of diesel fuel, taking into consideration the accessibility, financial, and technical suitability. Thus, because it is possible to lower the maximum toxicity and increase the life of the engines in comparison to diesel fuel, biodiesel is an alternative energy source that is appropriate and sustainable enough to be used (Verma et al. 2021). Possible developing countries like India are producing biodiesels such as mahua oil, neem oil, rice bran oil, Pongamia oil, soyabean oil, jatropha oil, etc., from non-edible oils (van Gerpen 2004). Rice bran biodiesel is mandatory because the large waste of rice bran is readily available in India.

Diesel engines that run on biodiesel may cut emissions the sulfur, hydrocarbon, and carbon monoxide exhaust emissions while increasing the NO_X because higher oxygen content is available in the biodiesel. The immense availability of oxygen is ascribed to complete combustion. Due to this, the temperature increases in the chamber, and it leads to nitrogen oxide. To accomplish these issues from biodiesel, the zinc oxide nanoparticle is used as an additive because it has catalytic properties, and due to this property, it reduces the temperature during the combustion. On the other hand, biodiesel has a few advantages and disadvantages like higher viscosity, lower volatility, and pour point. These disadvantages are ascribed to improper combustion (Sinha et al. 2008, Sivakumar et al. 2018). Although biodiesel is prepared under an Indian version of the American Standard ASTM D-6751 and the European Standard EN-14214 has previously been developed by the Bureau of Indian Standards (BIS) in the form of a standard known as IS-15607 for biodiesel (B 100). For motor petrol mixed with 5% ethanol and motor petrol blended with 10% ethanol, the Bureau of Indian Standards (BIS) has also released IS: 2796: 2008, which contains the specifications for both products.

The emission parameters of the diesel engine on neocons methyl ester of algae oil along with ZnO in the concentration of 25, 50, 75, and 100 ppm reported that BTE and HRR are enhanced and emission of CO and HC is reduced at 100 ppm ZnO nano additive (Kalaimurugan et al. 2021. Outcomes of the study on the efficiency of the engine's performance, and combustion parameters using 80 ppm zinc oxide with cottonseed oil biodiesel reported a better increment in performance and combustion characteristics along with a reduction in exhaust emission. Nayak et al. (2021) experimented by using the WCO biodiesel (B20) along with 3gm of ZnO, GO, and Al_2O_3 nano additives into fuel and compared the results with pure diesel. It was observed that the BTE has increased at a higher load for fuels with ZnO and GO nano additives, while the BSFC has been enhanced for fuels with ZnO and Al_2O_3 at a higher load. They reported that the exhaust emissions of carbon monoxide, hydrogen carbon, and nitrogen oxide are lowered in comparison to diesel fuel; however, smoke emissions are found to be higher for all blended fuel at full load. Gavhane et al. (2020) performed the findings after using the soybean biodiesel (B25) and 25, 50, and 75 ppm ZnO nanoparticles with surfactant at many variations of loads (0% to 100%) and compression ratio (18.5 to 21.5 mm). They found an increment in BSFC and BTE and decreased exhaust emissions like carbon monoxide, carbon dioxide, hydrogen carbon, and nitrogen oxide at a 21.5 mm compression ratio for 50 ppm ZnO nanoparticles added fuel. They also analyzed the HRR and MGT increased and the reduction in ignition delay at the same blended fuel and engine operating conditions. Rajak et al. (2022) conducted a comparative examination of the outcomes obtained from numerical and experimental investigations. The researchers introduced ZnO nanoparticles into diesel fuel at concentrations of 250, 500, and 1000 parts per million (ppm). The addition was carried out at different rotational speeds ranging from 2000 to 3000 revolutions per minute (RPM), fuel injection timings (FITs) between 19.50 and 24.50, and compression ratios ranging from 15.5 to 16.5 millimeters (mm). They found the increment in BTE and marginal improvement in BSFC after numerical analysis as compared to experimental data. However, the BSFC is found lower in the numerical analysis as compared to experimental data between 2750 to 3000 rpm speed. They mentioned a reduction in PMM at all compression ratios, and till 2500 rpm, speed and diminishment are found in smoke and There are no emissions whatsoever at any compression ratio. However, the emissions are larger when using gasoline combined with 500 ppm ZnO. They also saw an increase in EGT across all operating speeds and FITs. Praveena et al. (2020) studied the impact of grapeseed oil with 50 ppm and 100 ppm ZnO and CeO_2 nanoparticles with 1% span and 80% surfactant using the nano-emulsion process. According to their findings, the BTE and HRR values of 100 ppm ZnO and CeO_2 nanoparticles combined with grapeseed oil biodiesel fuel were much higher than those of GSBD. The study observed a decrease in the levels of NOx, HC, and CO when using fuel blended with 100 ppm ZnO nanoparticles. The study conducted by Khond et al. (2021) compares the results of the 200 ppm of Fe_2O_3, ZnO, and SiO_2 nanoparticles along with neem biodiesel (B25). They used diesel expert software to find the relation between the performance of the engine (BSFC and BTE) and also the relation between exhaust emissions (CO, NO_X, and Smoke) in their study. They found a reduction in BSFC for Al_2O_3 and ZnO blended fuel, while the BSFC is improved for SiO_2 and B25 blended fuel. When they checked for the result of BTE, they found an enhancement in BTE and maximum efficiency found for ZnO blended fuel as compared to B25, Al_2O_3, and SiO_2 blended fuel. They reported that the pollutant of NO_X increases for all blended fuel as well as CO_2 is enhanced from ZnO blended fuel only. However, CO and CO_2 are decreased from Al_2O_3 and SiO_2 blended fuels.

Fayad & Dhahad (2021) investigated the Al_2O_3 nanoparticles with butanol-diesel (B20) blended fuel in the concentration of 30, 50, and 100 ppm nanoparticles. The result reported HRR and an increase in cylinder pressure. They also mentioned the result of the performance, such as BSFC was reduced, and BTE was enhanced. The emission parameters such as HC, CO, and NO_X had been reduced for B20. They mentioned that the combustion is better for the butanol-diesel (B20) Al_2O_3 blended fuel. Yadav & Srivastava (2022) investigated diesel engines using SSCR technology that have met EURO-VI emission criteria rapidly. Uniform ammonia stream homogeneity improves droplet generation and evaporation across the SCR catalyst.

Table Cont....

An appropriate mixer may improve ammonia flow. In SCR systems, line mixers, swirl mixers, and combinations of both are common. However, line and swirl mixers perform best for SCR efficiency. This article discusses many ammonia flow uniformity methods. Due to reduced droplet residence time, a line-swirl mixer combination converts urea optimally. These mixers provide consistent flow and temperature. Uniform temperature distribution improves catalyst performance and reduces deposits. The study gives enough data for diesel engine NOx reduction researchers. A good mixer will reduce ammonia slip, helping diesel engine makers meet strict emission standards (Chethan et al. 2023). ASFAME synthesis is studied utilizing *Azadirachta indica* and *Simarouba glauca* oil blends with GO-CaO, a heterogeneous catalyst produced from discarded eggshells. Optimizing ASFAME production with varying catalyst concentrations provided 94.69% biodiesel from 0.5 g of GO-CaO. Additionally, the physicochemical properties of ASFAME were compared to conventional diesel, resulting in high-quality biodiesel meeting ASTM Standards 6751D. This work utilizes the eco-friendly heterogeneous catalyst GO-CaO to fulfill fuel demand and enable its recovery and reuse. This article enables small-scale biodiesel makers to get affordable catalysts and use leftover wastes for catalyst production. This project aims to reduce disposal issues and promote sustainability by combining various biodiesel oils.

PREPARATION OF RICE BRAN BIODIESEL

Srivastava et al. (2000) analyzed the literature review and identified various physical and chemical properties of rice bran oil fatty acids (FA). The chemical properties include Oleic (18:1) at 43.1%, Arachidic (C20:0) at 0.7%, Linoleic (18:2) at 32.2%, Linolenic (18:3) at 0.6%, and Free Fatty Acids (FFA) at 2.8%. Most of the physical properties have been tested in the fuel laboratory. Due to these properties, firstly, choose the 0.5% (W/W_{oil}) alcohol whose molar ratio is 6:1. Two types of base catalysts, such as NaOH and KOH, are selected, and after splitting the glycerol, water washing is applied to remove the impurities from the biodiesel. 1 L of hot distilled water ($70^{o}C$) was used for the catalyst removal and settled into the furnace under gravity. Through the application of these processes, two distinct layers were discovered. The lower layer reveals the presence of water and impurities, while the second layer signifies the presence of biodiesel. The pH of distilled water suggests that biodiesel does not contain any catalysts.

PREPARATION OF NANO FUEL BLEND

The Zinc oxide nanoparticles with a size of 40 nm are manufactured by Ad-nano Pvt. Ltd. Karnataka, India. Fig. 1 and Fig. 2 show the SEM and EDX pictures, respectively. Table 1 presents the parameters of ZnO nanoparticles. The process of blending diesel with biodiesel involves using a magnetic stirrer set at a speed of 1500 revolutions per minute (RPM) for 20 min. The ultrasonicator (24kHz) was used for 30 min to disperse nanoparticles at a concentration of 30 parts per million (ppm) into the biodiesel-mixed fuel. The prepared samples of fuel are stable after using the ultrasonication process. The properties of nano additive blended fuels are shown in Table 2, which is tested according to the ASTM standards. The fuel properties, as

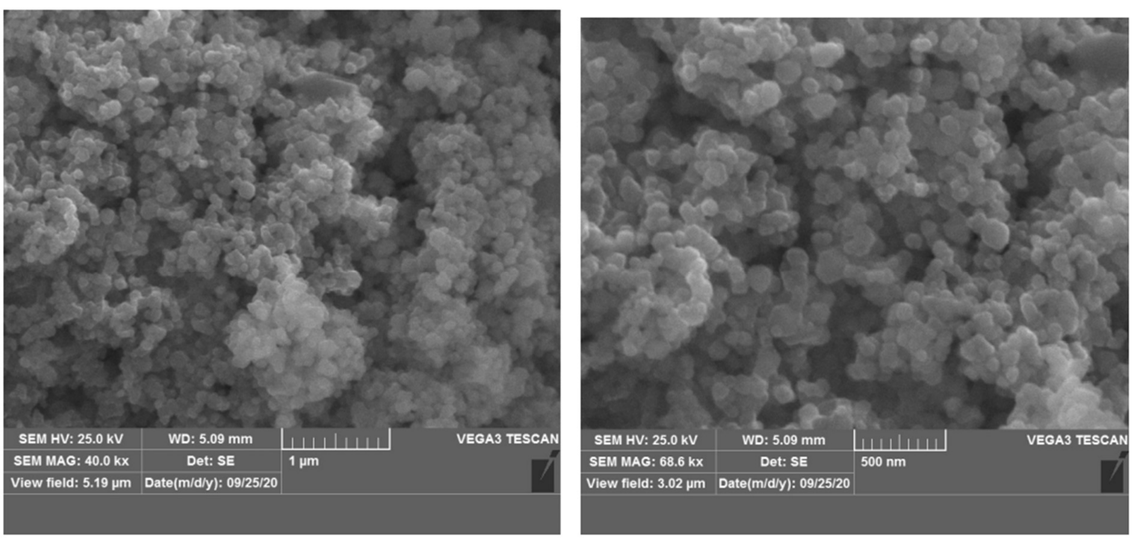

Fig. 1: SEM images of 40 nm ZnO nanoparticles.

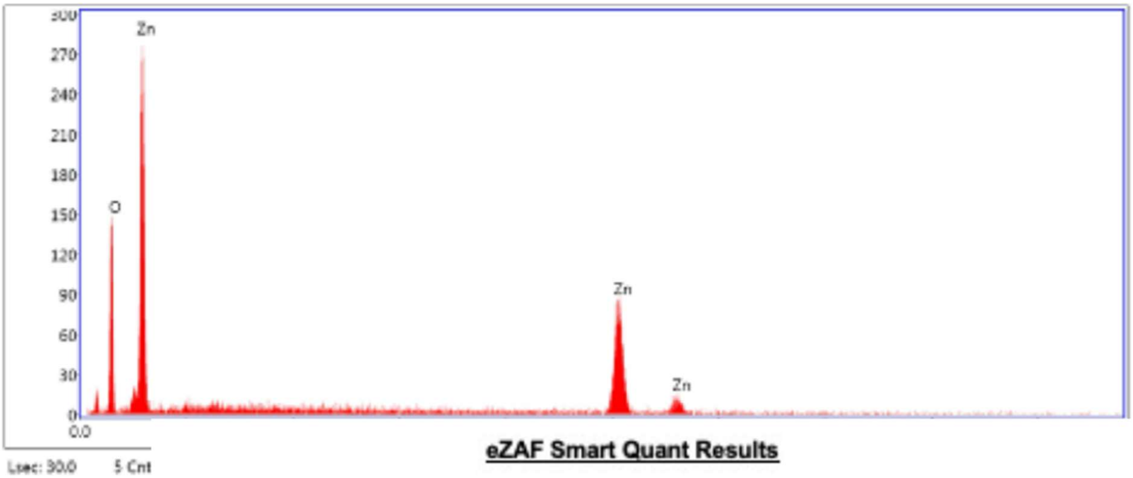

Fig. 2: EDX graph for the ZnO nanoparticles.

Table 1: Characteristics of zinc oxide nanoparticles.

Item	Value
Molecular Formula	ZnO
Purity	99.9%
Particle Size	10-40 nm
Molecular Weight	81.408 $g.mol^{-1}$
Bulk density	0.58$g.cm^{-3}$
SSA	100-120 $m^{2}\cdot g^{-1}$
Manufacturer	Ad-nano Technologies Pvt. Ltd.

in Table 2 measured by a hydrometer, bomb calorimeter, Viscometer, and Cleveland open-cup apparatus.

Zinc oxide nanoparticles exhibited smooth and homogeneous shapes, including spherical-like structures, cube-like structures, and layer-like structures. Furthermore, there was no agglomeration identified, which indicates that these nanoparticles are acceptable for treatment. Investigations using energy-dispersive X-rays on the nanoparticles of zinc oxide provide evidence that the samples are free of impurities. The ultra purity of the zinc oxide nanoparticles that were produced was quite high, as shown in Fig. 1.

Fig. 2 displays the elemental composition analyses of the ZNPs that were derived from the EDX plot of the SEM images. A high level of purity was validated for the ZNPs that were synthesized, as shown by the EDX spectra, which demonstrated that the samples contain the requisite phase of zinc and oxygen.

MATERIALS AND METHODS

This experimentation involves the use of a single-cylinder, four-stroke agricultural diesel engine manufactured in Bharat (Table 3). The engine operates at a consistent speed and compression ratio. The dynamometer is utilized for load and speed control, while the thermocouple heating filament (ranging from 0 kW to 3.5 kW) is employed to calculate data at different loads. There are five different types of temperature sensors, labeled T1 to T5, that are utilized for measuring various temperatures. These include the water inlet temperature, water outlet temperature to the engine, water outlet temperature to the calorimeter, exhaust gas temperature, and ambient temperature. The Airvisor 4 gas analyzer is utilized for measuring the emissions of CO, CO_2, HC, and NO_X (Fig. 3).

Uncertainty Analysis

Uncertainty analysis is important for finding out the exact value after experimentation. Various types of uncertainty

Table 2: Characteristics of all fuel samples.

Properties/fuel	D100 (Neat)	B10	B20	B30	B10ZnO30	B20ZnO30	B30ZnO30	Standard
Density, $kg.m^{-3}$, 15°C	837	839	847	852	839.2	848	854	ASTM D-1298
Heating Value [$MJ.kg^{-1}$]	44.0	43.6	42.90	40.05	44.01	46.23	46.54	ASTM D240
Kinematic Viscosity, 40°C	3.8	4.1	4.32	4.9	4.0	4.14	4.5	ASTM 7042
Flashpoint [°C]	74	185	188	76	83	85	86	ASTM D-93

Table 3: Key specifications of the diesel engine.

Item	Value
Engine manufacturer	Bharat
Rated power	3.5 kW
Engine Capacity	8 HP
Cooling Method	Water-Cooled
Injection Method	Direct Injection
Bore × Stroke	(87.5 × 110) mm.
Compression Ratio	17.5:1 mm
Speed	1500 RPM
Number of cylinders	1

(inaccuracies), such as weighting of nanoparticles, engine or test fuel components, some environmental effects, and calculation errors by humans, were found during the research work. The accuracies and inaccuracies are displayed in Table 4.

RESULTS AND DISCUSSION

Within this industry, we analyzed the performance results such as BSFC and BTE of diesel, as well as combustion parameters like EGT and emissions including CO, CO_2, HC, and NO_X. These are compared to the neat diesel fuel (D100). All these effects are measured under consistent conditions, including a constant speed and compression ratio of the diesel engine at four different loads: 0 kW, 1.5 kW, 2.5 kW, and 3.5 kW.

Table 4: Exploring the analysis of uncertainty.

Parameters	Accuracy	Uncertainty [%]
Electronic balance [ppm]	-	± 0.007
Heat release rate [$J.sec^{-1}$]	-	± 0.22
BTE	-	± 0.25
BSFC	-	± 0.30
CO	± 0.001	± 0.16
CO_2	± 10 ppm	± 0.002
HC	± 10 ppm	± 0.001
NO_X	± 10 ppm	± 0.002

Effect of All Fuel Samples on the Performance of the Engine

Effect on BSFC of nano additive mixed fuel: The BSFC is the major parameter of engine performance. The results of the BSFC are shown in Fig. 4. The results show an increase in BSFC for all fuel blends, except for B30 and B10 at

Fig. 3: Experimental Diesel engine image.

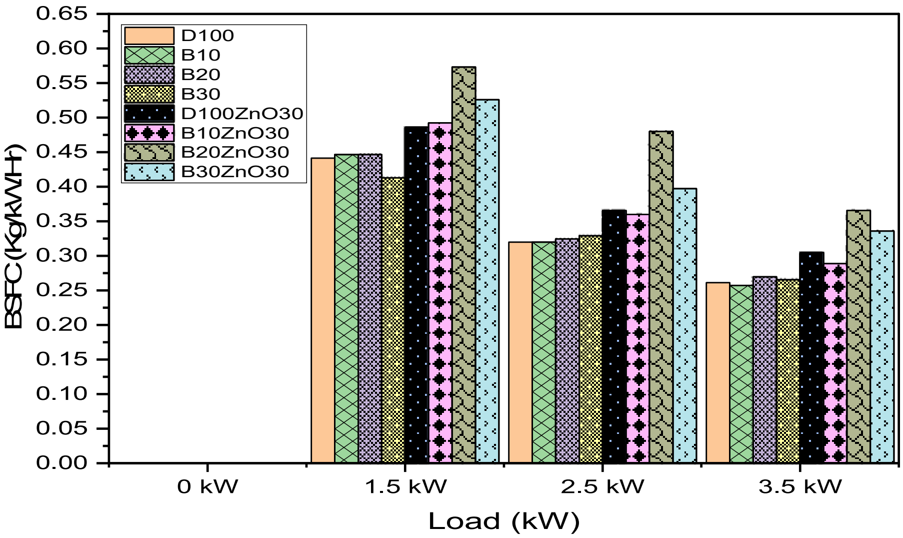

Fig. 4: Graph for Load vs BSFC.

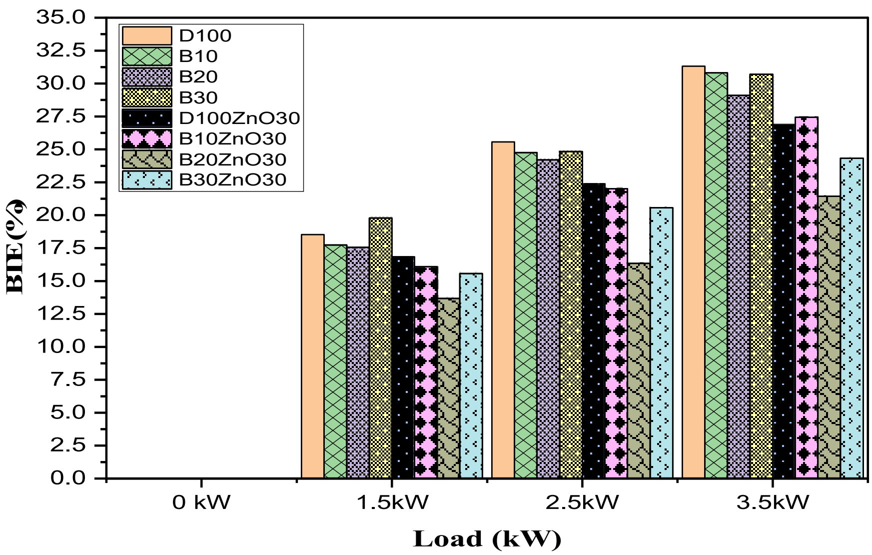

Fig. 5: Graph for Load vs BTE.

1.5 kW and 3.5 kW loads, respectively. The fuel consumption reached its highest levels at 29.86%, 50.04%, and 40% for the B20ZnO30 fuel blend when operating at 1.5 kW, 2.5 kW, and 3.5 kW loads, respectively, in comparison to neat diesel (D100). The improvements were demonstrated due to the utilization of Zinc Oxide nanoparticles, which contribute to enhanced oxidation. The addition of zinc oxide nanoparticles to a fuel significantly improves the combustion response in the combustion chamber. This is due to the superior volume-to-surface area ratio and high thermal efficiency of the nanoparticles, which increase the accessible volume for burning. Using the Zinc Oxide nano additive in the fuel blends improves the air-fuel ratio and decreases the ignition delay period. In addition, it enhances the flash point of the fuel blends, resulting in improved combustion.

Effect of nano additive blended fuel on BTE: The BTE increases when the loads increase. It depends on the dosage level of nanoparticles. If the dosage of nanoparticles improves, then BTE will increase (Fig. 5). The addition of ZnO nanoparticles lowers the ignition delay and evaporation time. The addition of nano additive improves the fuel-burning properties and air-fuel ratio of fuel. This causes fuel droplets to increase. Due to these droplets, fuel evaporates rapidly. This process affects thermal efficiency. At a 1.5 kW load,

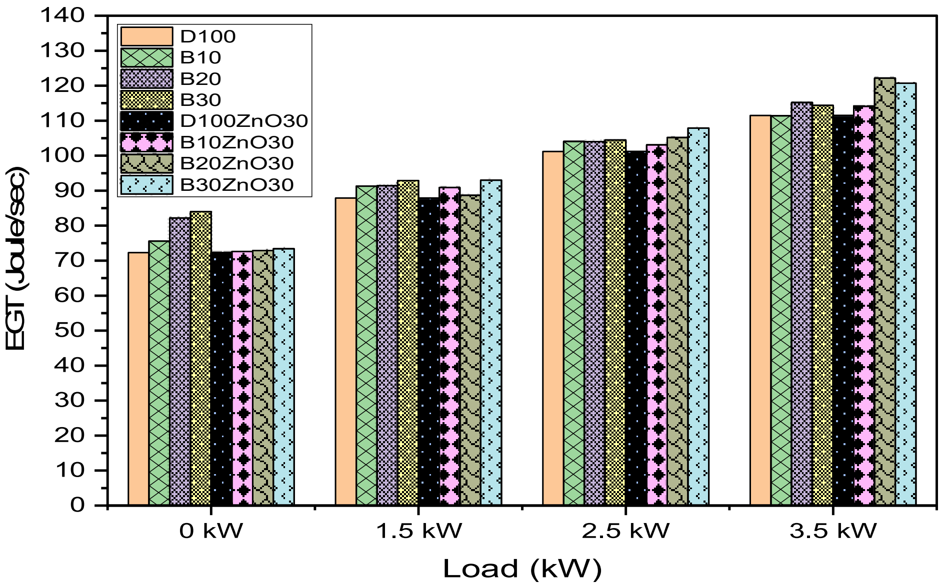

Fig. 6: Graph for Load vs EGT.

the use of B30 fuel resulted in a 6.79% increase in BTE compared to neat diesel fuel.

The Impact of Nano-Additive Mixtures on Engine Combustion

Examining the impact of nano additive blended fuel on EGT: Increasing the temperature in the combustion chamber improves the exhaust gas temperature (EGT). In this experimental study, the temperature of exhaust gas is higher for some blended fuels. The maximum EGT values for different fuel blends were recorded at various load levels (Fig. 6). B30, B30ZnO30, B30ZnO30, and B20ZnO30 fuel blends exhibited EGT values of 16.18%, 5.80%, 6.62%, and 9.59%, respectively, compared to neat diesel fuel (D100). The presence of ZnO in the fuel blends acted as a catalyst, controlling the temperature rise in the cylinder. Additionally, the high pressure inside the cylinder contributed to the increase in temperature. The temperatures of exhaust gas for D100ZnO30 fuel blends are identical to those of neat diesel fuel (D100) across all loads.

The Impact of Using Nano Additives on Exhaust Emissions from the Engine

The nano additive mixed fuel's impact on CO exhaust: Carbon monoxide is generated as a result of an increase in the temperature of the combustion chamber. A fuel's combustion response in the combustion chamber is considerably improved when zinc oxide nanoparticles are added to the fuel via the addition process. This occurs because of the nanoparticles' high thermal efficiency and higher volume-to-surface area ratio, both of which contribute to an increase in the volume that is potentially available for combustion. As a result of excessive oxygen and the higher reactive surface of ZnO, which improves the temperature, as well as pressure due to the higher heating value of fuel, which results in complete combustion, and due to the higher oxygen content, it converts the CO into CO_2, the maximum decrement in CO content for the D100ZnO30 fuel blend was found to be 80% at 0 kW load in this experimental study (Fig. 7). This was found to be the case when compared to neat diesel (D100). The carbon monoxide (CO) levels for various fuel blends, including B10, B20, B30, D100ZnO30, B10ZnO30, and B30ZnO30, at 1.5 kW, as well as B10 and B10ZnO30 at 2.5 kW, are equivalent to that of pure diesel (D100) fuel.

The impact of incorporating nano additives into gasoline on the release of CO_2 emissions: CO_2 is produced due to the higher oxidation of fuel during combustion. In this experiment, maximum diminishment in CO_2 is obtained from B10, B20, B30, and B10ZnO30 fuel blends that are 3.4%, 3.1%, 3.6%, and 3.7%, respectively, at 0 kW load, and CO_2 decreases 2.94% for B10 fuel blend at 1.5 kW as compared to D100 due to better atomization of fuel (Fig. 8). At a 2.5 kW load, the CO_2 value for B10 fuel blends is equivalent to that of neat diesel fuel in the experiment.

Effect of the nano additive blended fuel on HC exhaust emission: Because of the viscosity of the fuel's combination with air and the spraying of fuel within the combustion chamber, the hydrocarbon (HC) emission is mostly determined by these two factors. It involved determining

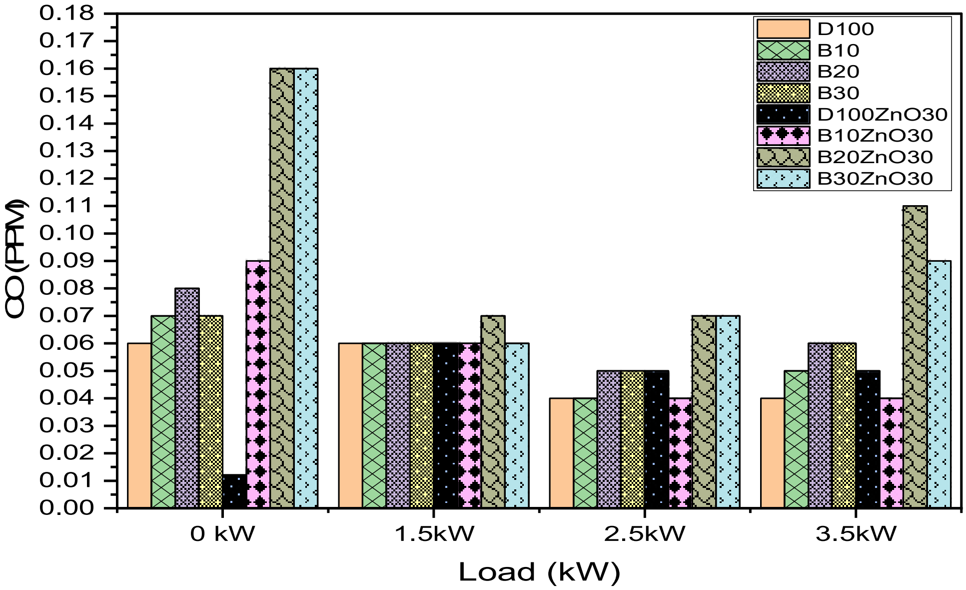

Fig. 7: Graph for Load vs CO.

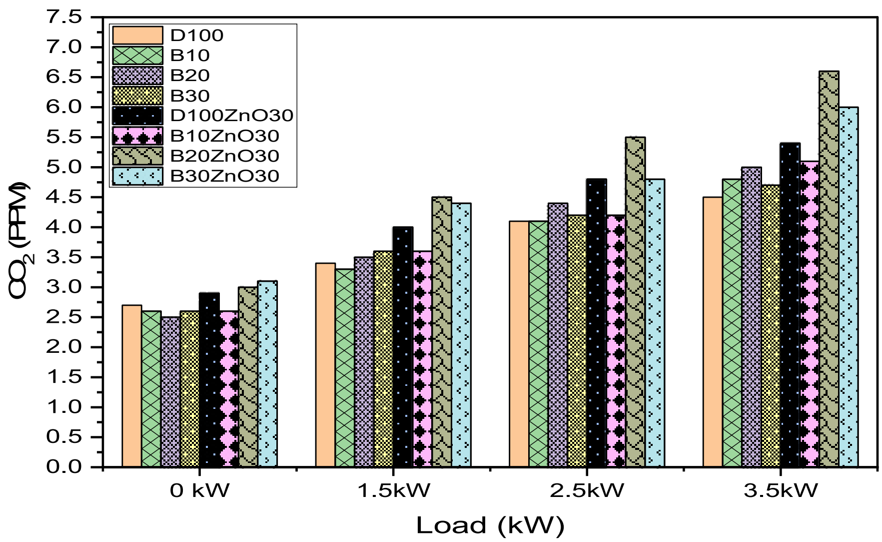

Fig. 8: Graph for Load vs CO_2.

the ratio of air to fuel, ranging from a lean mixture to a rich mixture. Certain fuel blends have demonstrated a decrease in HC emissions under various load conditions (Fig. 9). At 0 kW, 1.5 kW, and 2.5 kW loads, B10ZnO30, D100ZnO30, and D100ZnO30 showed significant reductions in HC levels when compared to neat diesel fuel (D100). The reason for the above phenomena is the addition of nano additives in the blended fuel, which effectively eliminated unwanted fuel and provided an excess of oxygen. Therefore, nanoparticles are commonly referred to as oxygen buffers that aid in enhancing the air-fuel equivalence ratio. When operating at a 3.5 kW load, the HC emission levels are higher for all blended fuels compared to neat diesel fuel (D100). This is primarily due to the higher viscosity characteristics of the blended fuels, which leads to difficulties in fuel spraying and ultimately results in poor combustion.

Effect of the nano additive blended fuel on NO_X exhaust emission: The emission of NO_X is influenced by the elevated temperature and pressure within the cylinder. It is directly related to the engine's loads. As the engine load increases, the

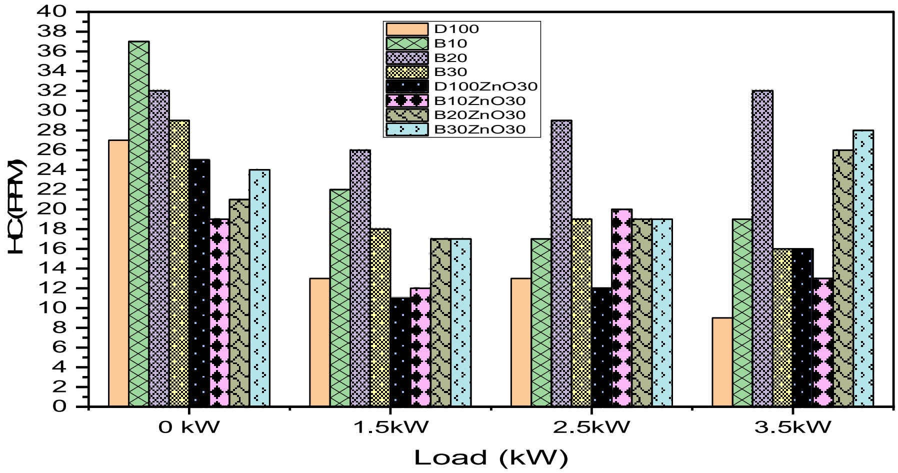

Fig. 9: Graph for Loads vs Hydrocarbon (HC).

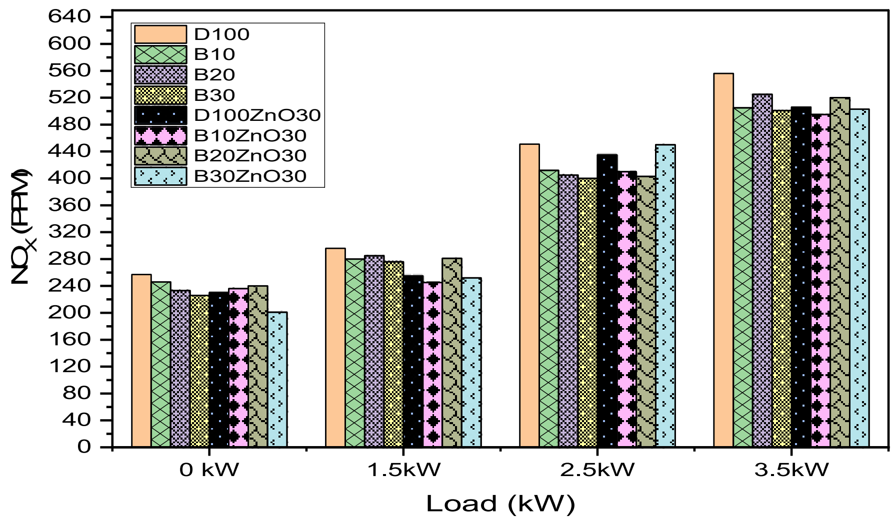

Fig. 10: Graph for Load vs NO_X.

NO_X levels will also rise. Fig. 10 illustrates the decrease in NO_X emissions when using all-fuel blends compared to neat diesel fuel (D100). The fuel blends B30ZnO30, B10ZnO30, B30ZnO30, and B10ZnO30 showed significant reductions of 21.78%, 17.22%, 11.30%, and 10.97% respectively at different power levels. The reason for the thermal stability of ZnO nanoparticles and their ability to promote shorter ignition delay, resulting in improved air-fuel mixing. Through their catalytic properties, zinc oxide nanoparticles can absorb oxygen content, resulting in a reduction in NO_X exhaust emissions.

CONCLUSIONS

This research examined the impact of adding a ZnO additive to biodiesel and diesel fuel blends on the performance, combustion, and exhaust emissions of a diesel engine. The data are presented in a columnized format below, comparing them to plain diesel.

- The BSFC is 29.86%, 50.04%, and 40% improved for the B20ZnO30 fuel at various loads due to the characteristics of the biodiesel.
- The Brake thermal efficiency value should be enhanced by increasing the concentrations of nano additives in fuel. The maximum 6.79% improvement is recorded on B30 fuel at a 1.5 kW load.
- The EGT shows a significant improvement of 16.18% thanks to the catalytic properties of ZnO and its large surface area.

- The highest reduction in carbon monoxide (CO) emissions for B20 fuel is 7.69% when the load is 0 kW, while the value of CO emission for B10 fuel is the same as that of plain diesel fuel when the load is 2.5 kW. This leads to an improvement in CO2 levels as well. Plantations of trees can help control emissions, but they are unable to control NOX, which directly harms the ozone (O3).
- The maximum reduction in HC is 29.2% and 15.38% for B10ZnO30 and D100ZnO30 because nanoparticles are the oxidation catalyst that improves the combustion property and leads to shorter ignition delay.
- Very good results were found for NO_X emission. NOx emission slightly decreases for the all-fuel blends at all loads. The better results of reduction in NOx emission are 21.78% and 17.22% found for B30ZnO30 and B10ZnO30 fuel blends respectively. Because of the excessive content in biodiesel, mixing the catalytic-based ZnO nanoparticles enhances the cylinder temperature. Nitrogen is converted into nitric acid, which causes to decrease in NOx content from the exhaust.

Thus, it has been summarized that Zinc Oxide nanoparticles are better additive, enhancing performance and reducing exhaust emissions. Zinc Oxide nanoparticles are efficient and improve concentration for better combustion results for future recommendation. The above-archived combination of biodiesel and nanoparticles seems to be the solution for reducing industrial pollution and reducing the related health hazards for its workers.

ABBREVIATIONS

RB	Rice bran	SEM	Scanning Electron Microscope
WCO	Waste cooking oil	EDX	Energy dispersive X-ray Spectroscopy
PMM	Particulate matter	MGT	Mean gas temperature
GO	Graphene Oxide	FA	Fatty acid
EGT	Exhaust gas temperature	HRR	Heat release rate
FFA	Free fatty acid		
GSBD	Grapeseed oil biodiesel		
FITs	Fuel injection timings		

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