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Research Article

Performance and Environmental Effects of CeO_2/ZrO_2 Nanocomposite in Triple Blend Methyl Ester of Pumpkin and Neem Seed Oil Dosed with Diesel on IC Engine

P. Shalini Priya Dharsini,[1] N. Ahalya,[2] S. Kaliappan,[3] S. Sekar,[4] Pravin P. Patil,[5] Varasala Pragna,[6] Gurusamy Pathinettampadian,[7] J. Isaac JoshuaRamesh Lalvani,[8] and Kibrom Menasbo[9]

[1]*Department of Physics, Government Arts College for Women, 636008, Salem, Tamilnadu, India*
[2]*Department of Biotechnology, MS Ramaiah Institute Technology, 560054, Bengaluru, Karnataka, India*
[3]*Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, Tamilnadu 601204, India*
[4]*Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, Tamilnadu 602105, India*
[5]*Department of Mechanical Engineering, Graphic Era Deemed to Be University, Bell Road, Clement Town Dehradun, Uttarakhand 248002, India*
[6]*Department of Mechanical Engineering, Aditya Engineering College, Aditya Nagar, Surampalem-533 437, East Godavari Dist, Andhra Pradesh, India*
[7]*Department of Mechanical Engineering, Chennai Institute of Technology, Chennai, 600069, Tamilnadu, India*
[8]*Faculty of Mechanical Engineering, Arba Minch Institute of Technology, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia*
[9]*Faculty of Mechanical Engineering, Arba Minch Institute of Technology, Arba Minch University, PO Box 21, Arba Minch, Ethiopia*

Correspondence should be addressed to Kibrom Menasbo; kibrom.menasbo@amu.edu.et

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The goal of this work is to evaluate the impact of CeO_2/ZrO_2 (CZ) nanocomposite materials on performance and emission characteristics of direct injection (DI) diesel engine fueled with ternary blends of pumpkin oil methyl ester (PME) and neem oil methyl ester (NME). The blend B20 (10% PME +10% NME +80% diesel) and various CZ nanocomposite blended fuels such as B20CZ25 (B20 +25 ppm CZ), B20CZ50 (B20 +50 ppm CZ), B20CZ75 (B20 +75 ppm CZ), and B20CZ100 (B20 +100 ppm CZ) were prepared and used for analysis. Pumpkin and neem seed oil were chose for this study due to noble economic feasibility, and they were transesterified with methanol and sodium hydroxide (NaOH) in order to get corresponding methyl esters. The experimental findings demonstrates that adding CZ nanocomposite improves brake thermal efficiency (BTE) and reduces brake specific fuel consumption (BSFC) at full load, as well as being beneficial in reducing harmful gases such as carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxides (NOx). The study suggested that CZ nanocomposite with ternary blend will be a viable new strategy for improving engine performance and lowering emission characteristics without modifying the engine.

1. Introduction

Internal combustion (IC) engines are most widely used technology in automotive industry. For more than a century, conventional diesel engines have been used in commercial and passenger cars, which are also joined in our modern life. IC engines are widely used for mobility. Apart from that the IC engines are used for agricultural, industrial and power sectors. With respect to long-term prospects of IC engine technology, oil dependence has been identified as a major issue due to fast depletion of crude oil. The increased price and pollution due to burning of petroleum fuel is also considered another drawback [1]. Fossil fuel combustion technologies are under review due to negative impact on environment including climate change by the emissions of hazardous gases such as CO, nitrogen oxides (NO_2), and sulphur dioxides (SO_2) [2]. Protecting environment from toxic gas substances is one of the very important targets particularly for industrialized countries. According to Coronado, almost 700 MT of CO, 150 MT of NO, 200 MT of solid particles, and 200 MT of $SO_2$are discharged into the atmosphere every year [3]. The transportation industry is the major responsible for emitting majority of these substances. IC engines are currently consuming around 85% of the world total energy, for which transportation engine constitute a major portion.

In most of the previous studies, biodiesel has similar combustion properties as petrodiesel [4, 5].As a result, it is extensively tested in IC engines and gas turbines to improve combustion performance and reduce pollutants with new novel combustion technology [6]. Biodiesel is the most appealing fuel for replacing fossil fuel in IC engines because it is nontoxic and biodegradable [7].Biodiesel are renewable energy source and has almost same functional properties as diesel fuel while burning inside the combustion chamber. Many studies have reported the use of biodiesel for engine operation and produced positive output [8, 9]. It can be utilized in engine directly without any design modification. It has grown in favor as a greener alternative fuel. Researchers used edible and non-edible feedstocks for preparing biodiesel with improved physicochemical properties [10]. Food-grade vegetable oils are more expensive feedstocks for biodiesel production. In addition to that, they affect the food chain significantly. So production of biodiesel without affecting food chain is the advisable one. Previously, Ashok et al. [11] used binary blends of *Calophyllum inophyllum* oil and diesel and utilized for engine operation with different blends such as B20, B40, B60, and B80. The study showed lower performance than diesel fuel for all blends with increased SFC. But the emissions of CO reduced for all blended fuels. Using cottonseed oil for DI diesel engine, Soloiu et al. [12] showed lower emissions of CO, HC and NOx. Selvan et al. [13] prepared biodiesel form algal, cotton seed and eucalyptus oils using transesterification process and used for engine analysis. Out of the selected 12 blends, AO10D (10% algal oil + 90% diesel) produced favorable results of 45% BTEthan diesel (37%) at half load conditions. The value of specific fuel consumption is reduced with reduction in CO_2 (2.3%), CO (22%), NOx (0.97%), and smoke (6.54%) emissions. Binary and ternary blends of yellow mustard oil with higher alcohols was prepared and used as fuel for IC engines by Yesilyurt et al. [14]. Engine tests exposed that increased amount of alcohol in the blends decreased the BTE of the engine with increased BSFC. Compared to diesel, alcohol blended fuels had lower exhaust gas temperature (EGT) and CO_2 emissions, but the results showed higher O_2 emissions due to the higher oxygen concentration in alcohol. Sudalaiyandi et al. [15] prepared ternary blends of linseed, rubber seed, and diesel blends for IC engines and used them as a fuel. The study used different percentage of biodiesel to create three separate B20, B40, and B50 blends. For biodiesel blends, the study found increased BTE with lower SFC. In comparison to neat diesel, ternary blends produced lower NO_2 and CO emissions.

Table 1: Properties of PME and NME.

Properties	PME	NME
Viscosity in cSt	5.8	6.1
Density in kg/m^3	905.35	902.10
Flash point in °C	172	170
Fire point in °C	195	191
Calorific value in MJ/kg	40.95	39.81

The main disadvantage using biodiesel for IC engine is the emission of NOx which enhances the formation of smoke. In many studies, the chemical substances derived from organic and inorganic components were utilized as additives for reduced smoke and NOx. CeO_2, Al_2O_3, ZnO, CuO, BaO_2, and RuO_2 are commonly used fuel additives. These additives are often used to improve combustion performance. Due to large surface to volume ratio, the nanotechnology had simplified the production of nano-sized molecules which helps to improve thermal and combustion properties [16]. Thirugnanam et al. [17] utilized NiO nanoparticle with palmyra oil biodiesel (B20) for TV1 type Kirloskar engine with different dosage. According to the study, dosage of 100 ppm NiO with B20 produced 1.3% more BTE than B20. Addition of nanoparticles with biodiesel blend resulted in a reduction of 12–22% CO and18–24% HC emissions. However, NiO with B20 raised emission of NOx marginally by 2–7%.Biodiesels from microalgae oil and diesel blends along with RuO_2 were analyzed by Kalaimurugan et al. [18]. The nano-RuO_2 was mixed with prepared B20 (20% microalgae oil +80% diesel) biofuel under different dosage. Comparing with diesel and B20, the biofuel with RuO_2 showed maximum in-cylinder pressure and heat release rate. The emission analysis showed decreased HC, CO, and smoke emissions with increased NOx. In performance point of view addition of nanoparticles improved the BTE of the engine with reduced BSFC. Manigandan et al. [19] experimentally tested the emission parameters of the engine with the aid of TiO_2, CNT, Al_2O_3, CuO, and CeO_2nano particles. These nanoparticles were dispersed at 100 ppm dosage level with diesel with the addition of 20% hydrogen. The blend with addition of CeO_2 and Al_2O_3 showed improved BTE, whereas the blend with CNT and TiO_2 nanoparticles showed reduced BSFC than other combinations. The addition of 50 ppm, 100 ppm, and 150 ppm zirconium oxide (ZrO_2) with water-diesel nanoemulsion showed increased BTE and reduced BSFC [20]. Tewari et al. [21] looked at the impact of multi-walled carbon nanotubes in biodiesel obtained from honge oil. The addition of nanomaterials boosted the BTE and NOx emissions while lowering CO and HC emissions.

From the invitations, it can be understand that there is a limited number of studies have focused on IC engine performance and emission studies utilizing ternary blends along

Table 2: Properties of the tested fuels.

Properties	D	B20	B20CZ25	B20CZ50	B20CZ75	B20CZ100
Viscosity in cSt	2.9	3.0	3.0	3.0	3.1	3.1
Density in kg/m^3	835	854	836	836	839	841
Flash point in °C	57	62	63	65	65	66
Fire point in °C	63	68	69	70	71	71
Calorific value in MJ/kg	43.62	43.10	43.43	43.67	43.75	43.84

with nanocomposite. In the present study, two different biodiesels were prepared from non-edible vegetable seeds and blended with diesel to prepare ternary blends. The study has been focused to examine the effect of CeO_2/ZrO_2 nanocomposite on the performance and emission characteristics of ternary blend fueled engine. The experimental results of BTE, SFC, emissions of CO, HC, and NOx were analyzed and compared.

2. Materials and Methods

2.1. Biodiesel Production. Pumpkin (*Cucurbitapepo* L) and neem (*Azadirachta indica*) trees were cultivated almost all over India. The required quantity of neem seed and pumpkin seeds were collected from local market in Chennai. The purchased seeds were prepared and dried in sunlight for 15 days. The general transesterification technique was used to make NME and PME from the neat neem seed and pumpkin seeds. India leads the world in neem seed output, with 4.4 lakh tonnes yielding 88,400 tonnes of oil and 3.5 lakh tonnes of cake every year. India has around 30 million neem trees with majority in Uttar Pradesh and Tamilnadu. The trees are cultivated along the roadsides, canal banks, and open farm lands. The kernel yield per tree varies between 8 and 24 kg. Indian mills extract between 24 and 27.5% oil, while village crushers extract between 18 and 22%. In India, roughly 50 to 60 trees are planted in a pumpkin form per acre of land. Every 4 to 6 months, 70 kg of oil seeds can be collected from a tree. This leads to the production of around 600 liters per acre tree. In south part of India, pumpkin seed are grown on about 400 to 450 acres of land. After atmospheric drying, the seeds were dried in a hot oven maintained at 60 °C for 60 min. Oil from the seeds was extracted separately through mechanical extraction process. The crushing process was repeated until the oils removed from the seeds completely. The extracted oil were filtered and settled for 2 days to remove further impurities. The raw oils were transformed to the corresponding methyl esters through homogenous catalyst transesterification process where glycerin is found as by product. Methanol (99% purity) was employed as an alcohol for this process. NaOH (97% purity) was favored as a catalyst. For this process, the reaction parameters such as process temperature and total time were fixed as 60 °C and 90 min, respectively. For transesterification process, 500 ml of neem seed oil was mixed with 100 ml methanol and 9 m of diluted NaOH solution. The mixed components were heated to 60 °C and held for 90 minutes. After reaching the holding time, the mixture was allowed to cool to room temperate. The presence of glycerin obtained at the bottom flask was removed manually. The obtained methyl ester was used to blend with diesel fuel. The same procedure was repeated to produce PME. Table 1 shows the properties of PME and NME.

2.2. Preparation of Ternary Blends. Pumpkin and neem seed oils have a higher free fatty acids level; thus, the production of biodiesel made from these oils have the same viscosity and good atomization characteristics like diesel fuel. The availability of the selected oils is plenty. So, blending these two biodiesels with petrodiesel offers a noble economic feasibility. The ternary blends are prepared by direct mixing. For engine analysis, B20 blend was created by mixing 10% of each biodiesel with 80% of diesel.

2.3. Synthesis of Nano Composite. The cerium-zirconium mixture was made with a cerium content of 5 mol% in the mixture. Separate proportions of each salts were dissolved in water and then combined. Solid urea as a fuel was added to the mixture at 1 : 1 ratio to the reaction components and then agitated until a clear solution was achieved. The mixture was kept in an oven maintained at 300 °C for nearly 30 minutes. The powers obtained at the end of the process were calcined by furnace by heating to 450 °C at the rate of 10 °C/min. The powders were uni-axially pressed at 100 MPa to obtain pellets of 2.5-cm diameter and 1-cm thickness for densification parameters.

2.4. Preparation of Nanobiodiesel. To prepare nanobiodiesel, the synthesized nanocomposite is mixed with prepared B20 biodiesel to get blends at different dosage of 25 ppm, 50 ppm, 75 ppm, and 100 ppm. Ultrasonic approach (UP400S, Hielscher, USA) was utilized for mixing the nanocomposite with B20 blend. This study limited to use maximum blend of B20. Before conducting the experimental tests, a trial reading was taken with blend more than 20%. In this study, the blend B20 shows the efficiency nearer to diesel. On the other side, the experiment utilizing B30, B40, and B50 shows higher loss in efficiency with higher emission of CO, HC and NOx. Based on the results, CZ nanocomposites with B20 were used for further analysis. Table 2 shows some imperative physical properties of tested fuel. Table 3 shows effect of nanoparticles with biodiesel on diesel engine performance observed from previous studies. From Table 2, it can be noted that the addition of nanomaterials with the biodiesel bend increased the calorific value and density. The calorific value of B20CZ50, B20CZ75, and B20CZ100 is observed more than baseline diesel fuel. On the other side, the addition of nanomaterials improved

Table 3: Effect of nano particles with biodiesel on diesel engine performance.

Engine type	Fuel	Nano particles and its size	Performance characteristics BTE	BSFC	Emission characteristics CO	HC	PM	NOx	Ref.
Kirloskar TV1	Calophyllum inophyllum methyl ester	Multiwalled carbon nanotubes	↑7.6% for B20 and 2.26%↑ for B20 with EGR	—	↓ for B20 with EGR	↓ B20 with EGR	↓ for B20	↓25.6%; For B20 with EGR	[22]
Kirloskar TV1	Waste cooking oil	MgO 20.76 nm	↑4.57%	↑28.2%	↓15.71%;	↓22.27%	↓4.68%	↑14.09%	[23]
Urea-SCR diesel engine	Waste frying oil- B20	$Mn_2O_3$and Co_3O_4	↑1.2% and ↑2.7%	↓4%	↓450 ppm and ↓500 ppm	—	—	↓40% and ↓14%	[24]
DEUTZ F1L511	Egyptian Jojoba oil	Al_2O_3 50–100 nm	↑15%	↓12%	↓80%	↓60%	↓35%	↓70%	[25]
AV1-Kirloskar	Pongamia methyl ester	Al_2O_3 100 nm	↑7%	↓50 ppm	↓using B25A50 and B25A100	↓using B25A50 and B25A100	—	↑for 0–5000 (ppm)	[26]
HATZ-1B30-2	Jatropha methyl ester-B20	Graphene nanoplatelets	↑25%	↑20%	↓65% (0–4000 ppm)	↓65%	↓55%	—	[27]
Kirloskar	Jatropha biodiesel	Al_2O_3 and CeO_2	↑12%	—	↓60%	↓44%	↓38%	—	[28]
Kirloskar TAF1	Calophyllum inophyllum biodiesel	1-pentanol and 1- butanol	↑	↑	↑	↑	↑49.5%	↓10% to 23%	[29]
Kirloskar	Canola oil methyl ester	Acetylferrocene, AcCp2Fe, and palladium (II)	—	—	↓60.07%	↓0–20,000 ppm	↓51.33%	↑	[30]
Kirloskar TV1	Pungamia pinnata biodiesel	Coconut shell 20 nm	—	—	↓0.01% vol	↓20% BD80%DF	—	↓18.56%	[31]
Cummins TC, Euro5	Palm oil methyl ester	Carbon coated aluminum	—	↓6%	↓19%	↓14.5%	—	↓6%–22%	[32]
Kirloskar TV1	Poultry litter	Alumina; 20–50 nm	↑	—	↓	↓	↑	↓	[33]

viscosity and density of the fuel. Density and viscosity are the two major factors restricting the atomization when fuel was injected into the engine cylinder. The flash and fire point of the fuel is also enhanced with the addition of dosage of the nanomaterials.

2.5. Engine Set up. Different prepare fuels were experimentally tested on a Kirloskar make single cylinder, constant-speed, water-cooled, DI diesel engine. The description of the engine set up is displayed in Table 4. The engine is loaded with electrical dynamometer. Before experimentation, the dynamometer is calibrated. The emissions of CO, CO_2, HC, NOx, and smoke were analyzed by AVL multi gas analyzer (AVL DiGas 444, AVL India private limited). For the analysis, one end of the cable is attached to the analyzer's inlet, and the other end is connected to the exhaust gas outlet. The engine is connected to the data acquisition system via an interface, and signals are logged in the attached computer. The engine is started and initially operated with neat diesel for 15 minutes. The output of the engine operated with neat diesel is considered reference. The tests are conducted using different fuels under the sample operating conditions by changing engine load from 0% to 100% at 25% load interval.

Table 4: Specification of engine setup.

Model and make	Kirloskar—TV1
Combustion type	Compression ignition
Compression ratio	17.5: 1
Dynamometer	Eddy current
Peak pressure	77.5 kg/cm^2
Fuel timing	23°BTDC
Rated power	5.2 kW
Rated speed	1500 rpm
No. of strokes	4
Stroke length	110 mm
Bore diameter	87.5 mm
Swept volume	661 cc
Cooling type	Water
Gas analyzer	AVL444

3. Results and Discussion

3.1. Performance Analysis

3.1.1. Brake Thermal Efficiency. Figure 1 depicts the variance of BTE in relation to applied load for the blended fuels diesel, B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100. The BTE reveals that how efficiently the energy in the fuel can be transformed as mechanical output. It is the ability of the combustion system. For all tested fuels, BTE increases as load increases. At full loading, the maximum BTE for diesel was 33.99%, 33.19% for B20, 35.02% for B20CZ25, 35.88% for B20CZ50, 33.66% for B20CZ75, and 32.79% for B20CZ100. Compared to diesel, BTE is slightly lower for B20 fuel all load. According to the previous reports, high density, and low heating value of the biodiesel blend inhibiting the proper atomization leading to improper combustion [34, 35]. Among all tested fuels, BTE has the lowest value when the engine is operated with B20CZ100 (32.79%) under full load condition. For B20CZ50, the highest value of BTE is attained. For B20CZ50, the maximum BTE of 35.88% obtained at full load condition which is 1.89% more than neat diesel. This could be owing to improved spray characteristics and dissolved oxygen in B20CZ50 resulting in better combustion with adequate air use. When compared to B20 addition of CeO_2 and ZrO_2 with blended fuel showed improved BTE. From the figure, it can identified that addition of nanocomposite would have a considerable impact on engine performance. The increased efficiency with nanocomposite is due to more oxygen, better evaporation and larger surface to volume ratio [36, 37]. The BTE of B20CZ75 and B20CZ100 fuel shows lower than B20CZ50. The decreased efficiency with increased dosage is may be due to increased viscosity of the fuel.

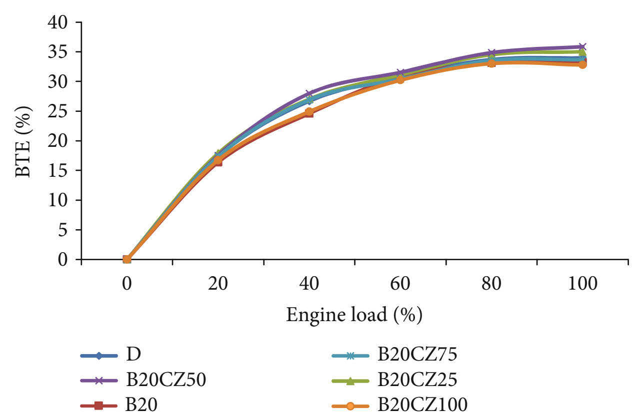

Figure 1: BTE vs load.

3.1.2. Brake Specific Fuel Consumption. The difference in BSFC regarding to engine load for CZ added biodiesel blends of diesel, B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100 has been reported in Figure 2. From the results, it can be understand that the BSFC for CZ blended biodiesel showed lower value than B20 fuel. For B20, the value of BSFC is recorded more than neat diesel. At higher load conditions the BSFC for diesel, B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100 are 0.28 kg/kWh, 0.33 kg/kWh, 0.27 kg/kWh, 0.26 kg/kWh, 0.29 kg/kWh, and 0.3 kg/kWh, respectively. It is observed that B20 biodiesels with 50 ppm CZ have superior properties than those of other concentrations. 50 ppm dosage with B20 showed lower BSFC than diesel due to enhanced qualities, and shorter ignition delay leads to complete combustion [38, 39]. The addition of CZ particles with fuel causes catalytic chemical oxidation within the combustion chamber resulted in reduction of BSFC. Compared to neat diesel fuel, 50 ppm of CZ particles with B20 fuel resulted in maximum of 28% reduction in BSFC. The nanocomposite with fuel act as an oxygen donor and probably produce complete combustion [40]. A similar kind of finding has been reported by Shaisundaram et al. [41].

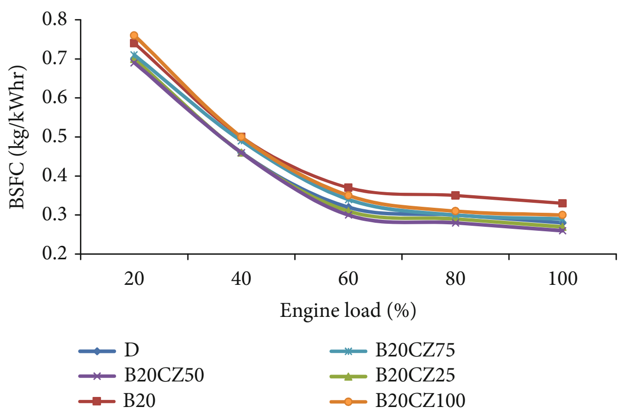

Figure 2: BSFC vs load.

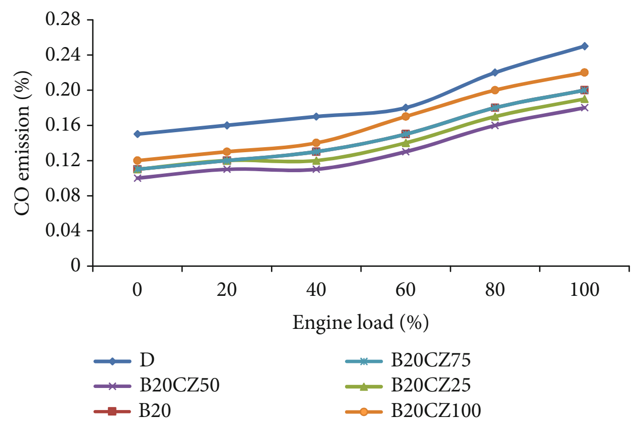

Figure 3: CO emission vs load.

3.2. Emission Characteristics

3.2.1. CO Emission. Figure 3 depicts the change in CO emission as a function of load for diesel B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100 distributed with CZ nanocomposite at four different dosage levels. The main reason for CO emission from the engine is incomplete fuel combustion. From the figure, it is noted that among various CZ proportions, higher reduction in CO was attained from 50 ppm CZ with B20 blend. This is could be the influence of nanoparticles in the fuel which produces better combustion. The emission of CO is recorded in increased trend as the load increases because the fuel provided to the engine is more at higher load leads to incomplete combustion [42]. At maximum load, the value of CO emissions for diesel, B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100 are 0.25%, 0.2%, 0.19%, 0.18%, 0.2%, and 0.22%, respectively. The amount of OH radicals available in the combustion reaction is proportional to the reduction of CO emission. Higher CZ concentrations produce more OH radicals, resulting in more CO reduction. Due to the minimal OH radical at 25 ppm, CZ exhibits a lesser reduction in CO emission then 50 ppm CZ concentration. Özgür et al. [43] found a similar pattern of findings using rapeseed methyl ester with MgO and SiO_2 nanoadditive.

3.2.2. HC Emissions. Figure 4 depicts change in HC emission as a function of load for various tested fuels. Like CO emission, the emission of HC for all loads is increased with increased load. At low load conditions, CI engines generally operate on leaner mixtures, and the emission of HC is caused by lack of evaporation of fuel due to low combustion temperature [44]. Though, at maximum loads, the emission of HC is increased because more quantity of fuel is admitted for burning. As seen in the figure, a significant reduction in HC was observed with the presence of CZ in B20 blend due to enhanced combustion. At higher load, the HC emissions for diesel, B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100 are 44 ppm, 46 ppm, 45 ppm, 43 ppm, 41 ppm, and 39 ppm, respectively. Addition of 100 ppm CZ with B20 showed a greater reduction in HC emission among the other proportions. It could be attributed to increased concentrations having higher reduction agents and make the combustion effectively [45]. The partial combustion of diesel at higher load is the main reason for higher HC emissions. Comparing with neat diesel the reduction of HC for B20CZ100 and B20CZ75 is 11.3% and 6.82%, respectively. The use of nanocomposite reduces HC emissions because they encourage complete combustion and perform as an oxygen supplier at maximum loads to permit proper fuel burning. This result is consistent with the majority of previous studies associated with nanoparticle in biodiesels [46, 47].

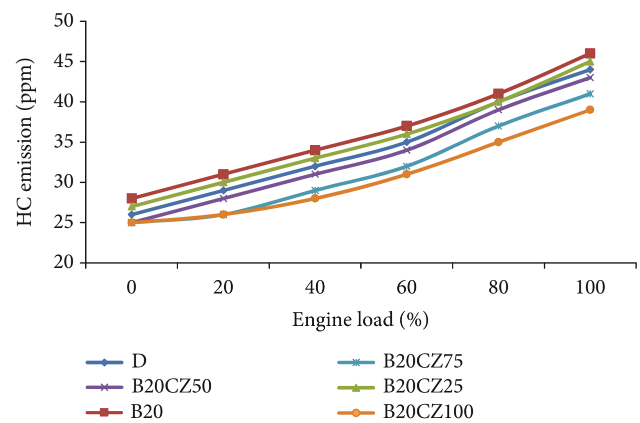

Figure 4: HC emission vs load.

3.2.3. NOx Emissions. Figure 5 demonstrates the difference in NO_x emission regarding engine load for diesel, B20 biodiesels with various proportions of CZ. Combustion chamber temperature is the main contributor for the concentration of NOx in exhaust gas. The emission of NOx is increased with respect to load due to increased combustion chamber temperature [48]. At higher load, the NOx emissions for diesel, B20, B20CZ25, B20CZ50, B20CZ75, and B20CZ100 and diesel are 992 ppm, 1039 ppm, 1021 ppm, 1000 ppm, 1035 ppm, and 1075 ppm, respectively. The NOx emissions for all blended fuels are more related to diesel due to increased oxygen concentration in the combustion chamber. The addition of CZ with fuel improves the

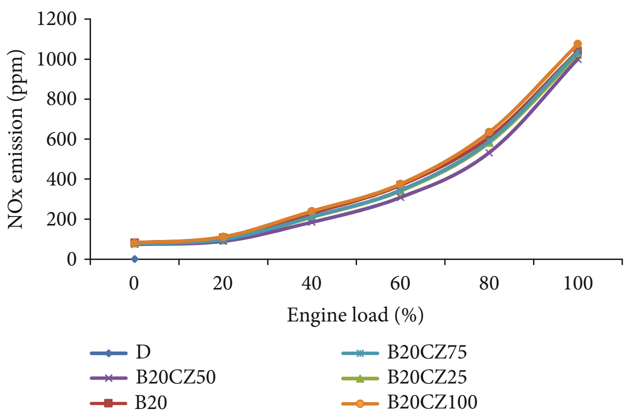

Figure 5: NOx emission vs load.

combustion process, significantly increasing in-cylinder pressure and temperature. The increased peak cylinder pressure due to oxygen buffering additives under various dosage levels increased excessive NOx emissions [49]. Compared to other dosage level of CZ, 50 ppm dosage of CZ showed reduction in NOx emission at all loads. It is noted from the figure that 50 ppm CZ has a greater tendency to decrease NOx due the scavenging activity. Similar trend of results was observed with annona methyl ester with antioxidant additives for NOx mitigation in compression ignition engine [50].

4. Conclusion

This work shows the evaluation of environmental impacts of internal combustion engines using nanocomposite as a fuel additive for ternary blend biodiesel- diesel. In this experimental work, CeO_2/ZrO_2 nanocomposite incorporated ternary blends of pumpkin seed oil, and neem seed oil methyl ester has been used as a fuel to test engine performance and emission characteristics. The use of B20 ternary blend and the addition of nanoparticles with B20 blend represent an excellent option on performance and emission point of view. The major findings obtained from this study are as follows:

(i) Dosage of 50 ppm CZ with B20 fuel showed increased BTE than diesel and B20 blends. B20CZ50 blend showed 5.56% and 8.1% of increased BTE than diesel and B20 blend

(ii) The 50 ppm dosage of CZ showed lower BSFC than diesel due to enhanced qualities and complete combustion

(iii) CZ dosed with B20 fuel reduced HC and CO emissions compared with diesel

(iv) The increased NOx emission with nanobiodiesel because of increased oxygen concentration in the combustion chamber

(v) From the findings, the nanobiodiesel obtained by combining pumpkin and neem seed oil methyl ester and CeO_2/ZrO_2

Given these findings, the produced fuel blends obtained by combining pumpkin and neem methyl ester can be considered a hopeful alternative fuel for usage in diesel engines. As a result, adding CeO_2/ZrO_2 nanocomposite to ternary biodiesel will be a viable new strategy for improving engine performance and lowering emission characteristics without modifying the engine.

Nomenclature

DI: Direct Injection
IC: Internal combustion
CZ: CeO_2/ZrO_2
D: 100% diesel
PME: Pumpkin oil methyl ester
NME: Neem oil methyl ester
B20: 10% PME +10% NME +80% diesel
B20CZ25: B20 +25 ppm CeO_2/ZrO_2
B20CZ50: B20 +50 ppm CeO_2/ZrO_2
B20CZ75: B20 +75 ppm CeO_2/ZrO_2
B20CZ100: B20 +100 ppm CeO_2/ZrO_2
BTE: Brake thermal efficiency
BSFC: Brake specific fuel consumption
CO: Carbon monoxide
HC: Hydrocarbon
NOx: Nitrogen oxides
SO_2: Sulphur dioxide
MT: Million tonnes
ppm: Parts per million.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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