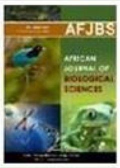
https://doi.org/ 10.48047/AFJBS.6.7.2024.1819-1831

AFJBS
African Journal of Biological Sciences
Journal homepage: http://www.afjbs.com



Research Paper Open Access

STUDY OF CI ENGINE PERFORMANCE AND EMISSION EVALUATION FOR SOYBEAN BIOFUEL WITH VARYING CERIUM OXIDE CONCENTRATIONS

Prakash M. Kadam[1], Dhananjay R. Dolas[2]

[1]Research Scholar, Mechanical Engineering Department, Jawaharlal Nehru Engineering College, MGM University Aurangabad, Maharashtra, India

[2]Associate Professor, Mechanical Engineering Department, Jawaharlal Nehru Engineering College, MGM University Aurangabad, Maharashtra, India

Article Info

Volume 6, Issue Si3, June 2024
Received: 19 April 2024
Accepted: 28 May 2024
Published: 22 June 2024
doi: 10.48047/AFJBS.6.Si3.2024.1819-1831

Abstract:

The shortcomings of fossil fuels and the Earth's increasing temperature have raised researchers' interest in alternative fuels for use in automobiles. In this study, biodiesel blends containing 20%, 40% and 60% soybean oil-based biodiesel (B20 and B40) along with cerium oxide (CeO2) at concentrations of 30, 60, and 90 ppm (denoted as C30, C60, C90) were added to pure diesel. The resulting blends were labelled as B20C30WOE, B20C60WOE, B20C90WOE, B20C30WE, B20C60WE, B20C90WE for B20, and similarly for B40, B60 and D100, with and without exhaust gas recirculation (EGR) (denoted as WOE and WE). The selection of cerium oxide and soybean biodiesel was based on their excellent thermophysical properties. The experimental trials were conducted on a constant speed and compression ratio of 18 in a CI engine for all the blends mentioned earlier, at variable loads of 0%, 25%, 50%, 75%, and 100%. The study focused on evaluating the performance and emission parameters. The brake thermal efficiency of B60C60WE is 39.26% higher and of B60C90WOE is 21.67% higher when comparing with and without EGR. This shows that as the concentration of cerium oxide increases at higher (100%) load, the thermal performance improves with EGR compared to pure diesel (D100). The lowest brake-specific fuel consumption (BSFC) was observed for B60C60WE at full load in comparison to diesel. The different exhaust gases were analyzed by an AVL gas analyzer, and it was observed that the addition of cerium oxide mixed in soybean oil helps to minimize emissions such as HC, CO, CO_2, and NOx in biodiesel blends compared to pure diesel. This improvement is due to the combined effect of oxidation and the thermal properties of cerium oxide.

Keywords: *Biodiesel, Emissions , Break specific fuel consumption*

1. INTRODUCTION

As the global population grows, more

people own vehicles, leading to increased emissions of oxides of nitrogen (NOX) and greenhouse gases; NOx is produced when fuels burn at high temperatures and contribute to harmful effects like ozone smoke, acid rain and reduced water quality fast the fuel burned. A diesel engine uses a mix of diesel and 20% biodiesel, along with different amounts of exhaust gas recirculation. They found that using 20% biodiesel with 20% Exhaust gas recirculation (EGR) made the engine less efficient, producing less power from the same amount of fuel. It also used more fuel and produced fewer NOx emissions, which are harmful pollutants, increasing EGR levels and slightly increasing emissions like carbon monoxide, hydrocarbon, and smoke [1]. Using biodiesel, which contains oxygen, can also raise NOx emissions. The EGR is used in diesel engines to solve this issue. EGR reduced NOx by lowering oxygen levels in the combustion chamber.In this study, researchers tested a Mitsubishi diesel engine using palm-biodiesel fuel and EGR. They found that using biodiesel with EGR decreased engine power and torque, increased fuel consumption, and lowered NOx emissions. There was a slight increase in emissions like CO2, CO, and particulate matter [2]. Researchers studied the best mix of aluminium oxide, carbon nanotubes and silicon oxide nanoparticles in diesel fuel for a Yanmar TF 120 M engine. They used BOX-Behnken's response surface method to find the ideal combustion of these additives and engine load to reduce fuel consumption, nitrogen oxides (NOX), and hydrogen (HC) emissions [3]. They found that the best results came with an aluminium oxide concentration of 45.62 PPM and the engine running at 50% load. This combination gave the highest desirability regarding engine performance and emissions. Researchers tested three types of fuel blend in an engine: MEME20, MEME20 with TiO2 nanoparticles added, and MEME20 with 25% TiO2 nanoparticles added. They also used 20% exhaust gas recirculation with different flow rates. Compared to using just MEME20 fuel, adding Tio2 nanoparticles increased BSFC by 3.6%, and adding TiO2 nanoparticles increased by 2.8% at full load. When TiO2 nanoparticles are added, emissions of hydrocarbons and carbon monoxide decrease. However, smoke emissions increased by 12.23% with MEME20+25TiO2 and 20% EGR with 35% urea injection compared to MEME20 fuel at maximum load NOx emissions decreased by 17.11% to 60% with fuel blends and EGR combustions. (Radhakrishnan Lawrence et al., 2020). This study examined how changing the compression ratio and exhaust gas recirculation (FGR) rates affected a diesel engine using 20% mango seed methyl ester (MEME20) fuel. When the compression ratio was increased to 22.1. At full load with MEME20 fuel, brake thermal efficiency was a 7.4% boost. Moreover, carbon monoxide emissions decreased by 33.3%, hydrocarbon emissions dropped by 40%, and smoke opacity decreased by 7.1% compared to using MEME20, with a compared ratio of 18.1[5]. In this experiment, researchers investigated the effects of introducing hydrogen, nitrogen and exhaust gas into the inlet manifold of a CI engine. The engine was a four-stroke, single-cylinder, water-cooled diesel engine operating at 1500 rpm. H2 and N2 were introduced into the inlet manifold using a high-pressure cylinder via water and air-based flame arrestors at 2 bar pressure. The optimized flow rate of H2 was determined, and then various flow rates of N2 were tested along with optimized exhaust gas recirculation and H2 flow rates [6]. In this study, researchers examined how adding multiwalled carbon nanotubes (MWCNTs) and using exhaust gas recirculation affected a diesel engine running on B20 biodiesel made from Calophyllum inophyllum. MWCNTs were added at 40 parts per million (ppm) to the B20 biodiesel and properly mixed using an ultrasonic or. The results showed that using MWCNTs alone led to a 7.6% increase in brake thermal efficiency. When EGR was used alone, there was a 2.42% decrease in efficiency, but when both MWCNTs and EGR were used together, there was a 2.26% increase in efficiency. The B20MWCNT40 fuel showed the highest cylinder pressure and heat release rate. Additionally, using MWCNTs decreased nitrogen oxide emissions by 25.6% to 29.7% [7]. Ozer and Erkan [8] investigated the effect of blending 20% soybean biodiesel with diesel fuel and using exhaust gas recirculation at rates of 5%,10%, and 15%.they conducted experimenters on a single cylinder four stroke diesel engine at a constant speed of 2200rpm. The results on a cylinder-stroke diesel engine at a constant speed of 2200 rpm show that combining biodiesel and EGR increased both the maximum heat release rate and the maximum cylinder pressure during combustion [8]. Chauhan et al. [9] looked into adding hydrogen gas directly into the intake manifold of a diesel engine running on biodiesel. They also adjusted the engine EGR system to control the EGR ratio and temperature more accurately. This study tested a four-stroke vertical single-cylinder diesel engine running at 1500 rpm using an eddy current dynamometer. The engine had a static injection timing of 20 ºBTDC and operated at a pressure of 250 bar; researchers applied selective catalytic reduction and varied exhaust gas temperature to study their effectiveness in reducing NOx emissions compared to a conventional engine setup. They found that EGR improved [10]. In this investigation using C20 fuel with 25ppm and 40ppm of TiO2 nano-additives, combined with 30% exhaust gas recirculation resulting in a 2.8% increase in BSFC, a 6.5% reduction in BSFC while maintaining NOx emissions at diesel levels, additional the inclusion of TiO2 nanoparticles led to further reduction in NOx emissions by 17.34% and 21.83% respectively compared to using C20D alone [11]. In this study researchers compared two engines one with a rotary fuel injection pump electronically controlled and other with a common rail injection system. They optimized both engines with different exhaust gas recirculation strategies and tested them under various transient conditions [12]. In modified direct ignition engine tests were carried out at different hydrogen ratios 0.5%, 5%, 10% and 25% and exhaust gas recirculation rates 0%, 5%, 10% and 20% to analyze combustion and emission characteristics. An additional 5% TiO2 was added to enhance combustion and reduce emissions. The result showed a 15% increase in torque with hydrogen addition, which improved mechanical efficiency due to a more comprehensive throttle opening. Nitrogen oxide emissions decrease with hydrogen fuel. Further tests on injection pressure revealed higher efficiency at 4 Mpa with reduced NOx, indicating shorter flame development [13]. This study mixed 20% Calophyllum Inophyllum biodiesel with 80% diesel to create B20 fuel and added TiO2 nanoparticles at a dosage of 40 ppm to form B2040TiO2 tests were conducted with B20, B2040TiO2, B20+20% EGR, and B2040TiO2 and B2040TiO2 +20% EGR. However, a decrease with B20+EGR, CO and HC emission decreased with TiO2 nanoparticles but increased with EGR. Smoke emission was notable with B20+20% EGR and B2040TiO2 +20% EGR; NOx emissions decreased with EGR but increased with TiO2 nanoparticles. The study concludes that B20 with Tio2 nanoparticle and EGR exhibits superior engine performance and reduced emissions [14]. N-octanol blends up to 30% with fossil diesel showed promising results in single-cylinder direct injection diesel engines; it prolonged ignition delay, increased peak of in-cylinder pressure and heat release rates during pre-mixed combustion, and improved brake thermal efficiency while reducing break-specific fuel consumption. Additionally, it decreased emissions of smoke, NOx, HC and CO, with

NOx and smoke emissions remaining low at all exhaust gas recirculation (EGR) rates. However, both BTE and BSFC were negatively impacted at higher EGR rates, while HC and CO emissions increased overall; n-octanol demonstrated potential as a sustainable fuel alternative for diesel [15]. Investigate the addition of alumina nanoparticles 40 ppm to a Calophyllum inophyllum biodiesel blend (CIB20) improved BSFC by 5.04% and 7.71% compared to CIB20 and CIB20ANP40+20% EGR fuels, respectively. CO and HC emissions were reduced with alumina nanoparticles, and smoke opacity decreased by 7.3% compared to CIB20, CIB20ANP40, and CIB20+20% EGR fuels, respectively, at full load conditions [16]. The study investigated the impact of blending low-viscosity biofuels, specifically pine oil and orange oil, with jatropha methyl ester (JOME), combined with EGR; blends of JOME with 30% volume, and Orange oil were tested at 10%, 15% and 20% EGR rates across various load conditions and base fuels. Results showed that the JOME operation increased NO emission by 4% and reduced smoke opacity by 10% compared to diesel at maximum load conditions. However, JOME with low viscosity biofuels reduced smoke, so blending of EGR and JOME70+PO30 and JOME70+ O30 helped reduce NO emissions with a slight increase in smoke opacity. The optimal configuration considering the NO smoke trade-off was found to be JOME70O30+EGE, where NO emissions were reduced by 14% and 11% compared to JOME and Diesel, respectively, while smoke opacity decreased by 5% and 15% compared to JOME and diesel at maximum load conditions [17]. The study investigated neat lemongrass oil as an alternative fuel in compression ignition engines. LGO25, cerium oxide blended emulsified LG20 with exhaust gas recirculation, compared with standard diesel and LGO25 blends. The combustion of DEE-added nano-emulsified LGO25 with EGR significantly reduced NOX and smoke emissions by 18.18% and 33.33%, respectively, compared to LGO25 [18]. Investigate the increasing atmosphere pressure, which improves diesel engine power performance and economy, with improvements ranging from 1.5% to 11.7% across different loads. Smoke emissions increase with increasing EGR rate, while NOx emissions decrease, HC and CO emissions decrease with increasing EGR rate [19]. This research proposal focuses on blending 30% palm biodiesel with 70% diesel b30 along with 25ppm TiO2 nanoparticles in an EGR system. At higher engine loads, smoke emissions from PBNEGR are lower than PB-EGR, and the synergistic effect of nanoparticles, biodiesel, and EGR enhances performance while minimising exhaust emissions [20]. Researchers investigated the effect of a blend containing MWCNT at 40 ppm with a 20% triazine-capped spherical Activated Carbon with EGR rates on various performance parameters of CI Engine. The fuel blend MWCNT 40ppm B20TCSAO has lower emissions than diesel without EGR. Moreover, BTE is increased compared to diesel when 5% EGR is applied [21]. The fuel sample was tested using rice bran biodiesel blended with ceria and zirconia nanoparticles. Experimental was done by using B30, B30+15% EGR, B30+50CeO2 15% EGR, B30+50ZrO2+15%EGR and B30+25ZrO2+25CeO2+15% EGR. BSFC was increased by 8%, BSFC by 9%, heat release rate by 4.3%, and cylinder pressure by 2.8%.exhaust emissions decreased by 30%, 19% and 13.3% CO, HC and NOx [22]. A study on EGR rates on diesel engines with a B16M20 mixture found that adding 50ppm and 100 ppm nano-TiO2 to B16M20 reduced BSFC by 6.47%, 100 nano-TiO2 with 10% EGR improved BTE by 4.53% compared to pure diesel 100 ppm nano-TiO2 with 20% EGR lowered NOX levels by 26.48%, Higher EGR rates led to increasing soot levels. However, pressure injection reduced soot emissions from B16M20 by 28.57%, and the concentration of 100 ppm nano-TiO2 PM decreased by 59% compared to diesel alone. Soot oxidation was improved by EGR and TiO2, with the latter producing more reactive soot than diesel alone [23].

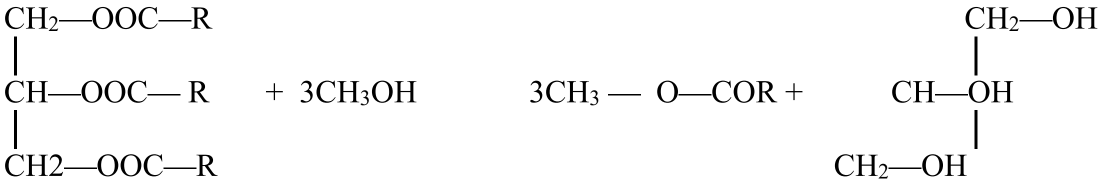
Table 1.

Ref.	Nano Addtives/ Base fuel	Concentration (ppm)	BSFC (%)	BTE (%)	CO (%)	HC (%)	NOX (ppm)	SMOKE (%)
[24]	Titanium dioxide (TiO2)/Acacia Concinna biodiesel (40% by vol.)	150	3.25↑	18.42 ↑	-	38 ↑	-	20↑
[25]	ZnO/ Waste cooking oil	90.9	30.75	13.92 MJ/kWh	0.057↓	34.68↓	717.2↓	-
	100 ppm ZnO/10% SB concentration, 20%water concentration	100	41.62 ↓	13.74 ↑	25↓	11.5↓	-	3.9↓
[26]	Nickel Oxide/Neem biodiesel blend of 25% (NB25)	25,50	24.6↓	17% ↑	1.6 ↓	22.41↓	5.1↓	-
[27]	AlO2/Methyl Ester of Jatropha	30	35.2↓	-	0.08↓	-	20 ↓	-
[28]	Carbon Nano Tubes/neem biodiesel-fueled	500, 100	20.3↓	14.2↓	5.9↓	6.7↓	9.2↓	7.8↓
[29]	CeO2/neat palm oil methyl ester	12, 20, 30	20↓	10↓	3.6↓	4.2↓	3.8↓	6.4↓

2. Material and Methods

2.1 preparation of soyabean biodiesel

Soybean biodiesel is prepared by transesterification, where vegetable oils or animal fats react with methanol or ethanol in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide. This reaction converts the triglycerides in the oils or facts into fatty methyl ester, which constitutes biodiesel, and glycerol as a by-product. Sodium Hydroxide acts as a catalyst by facilitating the reaction and increasing its rate without being consumed in the processes.



$$\begin{array}{l} CH_2—OOC—R \\ | \\ CH—OOC—R \\ | \\ CH2—OOC—R \end{array} + 3CH_3OH \qquad 3CH_3—O—COR + \begin{array}{l} CH_2—OH \\ | \\ CH—OH \\ | \\ CH_2—OH \end{array}$$

Triglycerides Methanol Biodiesel Glycerol

2.1 Feasibility of Soyabean biodiesel

Biodiesel coursed from plants like soyabean

Soybean has rapidly become the top oilseed crop in India, with approximately 10 million hectares dedicated to its cultivation. India is divided into five agro-climatic zones suited for soybean production, highlighting its widespread adaptability across the country. Soybean growing in states like Maharashtra, Madhya Pradesh, Rajasthan, Karnataka, Andhra Pradesh, and Chhattisgarh surpassed other oilseeds in area and production. It is mainly grown as a rain fed-crop in vertosols and associated soils; biodiesel is environmentally friendly. It produces fewer emissions and pollutants, contributing to lower greenhouse gases and cleaner air.

2.2 Selection of Soyabean biodiesel and nanoparticles

In the present investigation lower-level blends of soyabean

Biodiesel and nanoparticle cerium oxide have been used. The concentration of cerium oxide and biodiesel is used for the single-cylinder diesel engine. Biofuel has low emissions and performance and is an effective solvent without engine modification. Biodiesel has still more significant greenhouse gas benefits than regular diesel fuel.

3. Experimental set up

A single-cylinder diesel engine, powered at 5.2 kW and running at a constant speed of 1500 rpm, was used for testing. It was equipped with a piezo-electric pressure sensor to measure cylinder pressure and connected to an eddy dynamometer for break load, as shown in Table 1. Exhaust gas emissions were analysed using an AVL 444. Smoke opacity was measured with an AVL-437C smoke meter. Tests were conducted with diesel and biofuel with and without EGR at various load conditions. EGR reduces NOX emission by replacing some fresh air in the combustion chamber with exhaust gases, lowering the oxygen concentration and increasing the mixture's specific heat capacity, resulting in decreased NOx emissions percentage, the mass percentage of recirculated exhaust in the total intake mixture.

$$\%\ \mathrm{EGR} = \frac{\text{Mass of air in without EGR} - \text{Mass of air in with EGR}}{\text{Mass of air in without EGR}} \tag{1}$$

Table 2. list of instruments and their range, accuracy, and uncertainty

Instrument	Measurement	Range	Accuracy	Uncertainty
AVL DI Gas Five gas analyser	CO	0-10% Vol.	±0.03%	±0.2%
	CO_2	0-20% Vol.	±0%	±0.15%
	HC	0- 20,000 ppm	±10 ppm	±0.2%
	O_2	0-22% Vol.	±0.1%	±0.5
	NOx	0-5000 ppm	±50 ppm	±1
AVL 437 Smoke meter	Opacity	0-100	0.01	±1%

4 Results and discussion

EGR is a common and effective way to lower NOx emissions in diesel engines using biodiesel. It works by sending some of the exhaust gas, which contains CO2, back into the engine during combustion. This helps to reduce the engine's temperature and NOx emissions. It is a simple and effective method. A valve in the intake manifold controls the recirculation of exhaust gas. The flow rate of EGR is calculated by measuring the concentration of CO2 in the exhaust and intake manifold. The following equation calculates the EGR rate.

$$EGR(\%) = \frac{\%\ \text{of CO2 intake}}{\%\ \text{of CO2 exhaust}}\ X\ \ 100$$

In this study, we utilize an exhaust gas analyzer to quantify the CO2 emitted through the exhaust manifold and tailpipe after combustion. Through experimentation, we adjusted the exhaust gas recirculation within the range of 20% for all the fuels. Subsequently, these results are obtained from diesel engines with and without EGR due to the impact of EGR on emissions for different fuel compositions.

Characterisation of CeO_2 nanoparticle

CeO2 nanoparticles were synthesised using the solvothermal method. The size of the CeO2 nanoparticle was 20nm, which was used in this study.

- **Emission characteristics**

CO emissions

Figure 1 shows the variation of CO emission concerning various loads by adding the CeO2 nanoparticle. It is observed that at D100C30, having 14.25% reduces the Emission with EGR and 10.34% without EGR at full load when the nanoparticle is blended with pure diesel. Moreover, D100C60 has a 10.34 % reduction in CO emission with EGR while a 6.25 % reduction without EGR at full load.

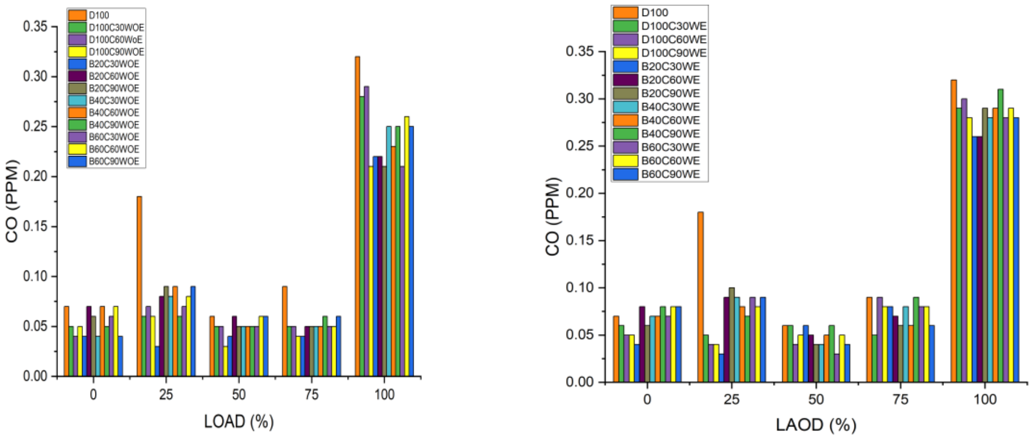


Figure 1. Variation of CO emission with respect to load for different fuel blends at (a) with EGR (b) without EGR.

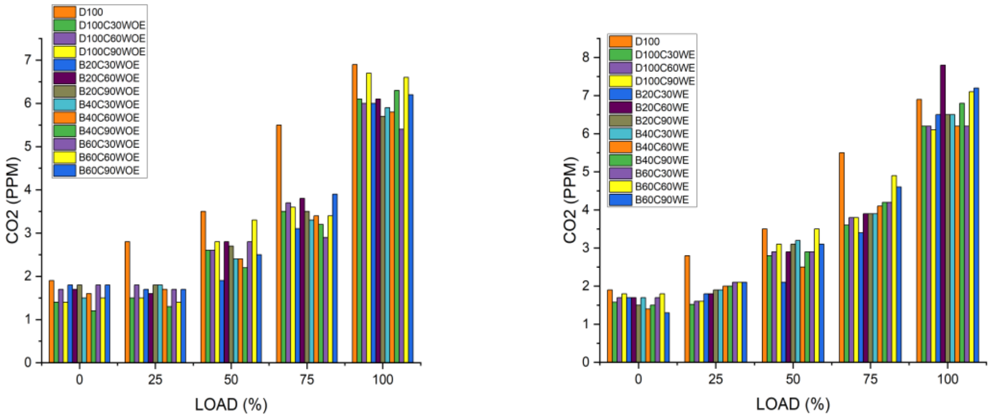


Figure 2 shows the variation of CO2 emission with respect to load for different fuel blends at (a) with EGR (b) without EGR

Figure 2 shows the variation of various blends with different loads. It is observed that D100C90, having 2.98%, reduced the CO2 emission with EGR, while the same blend reduced 13.11% without EGR at full load conditions. B20C90 had 21.06 % reduced emission with EGR, while at full load, 10.12% reduced the CO2.and B40C90 had 37. 14% reduced without EGR at full load, while 6.15% reduced CO2 without EGR.

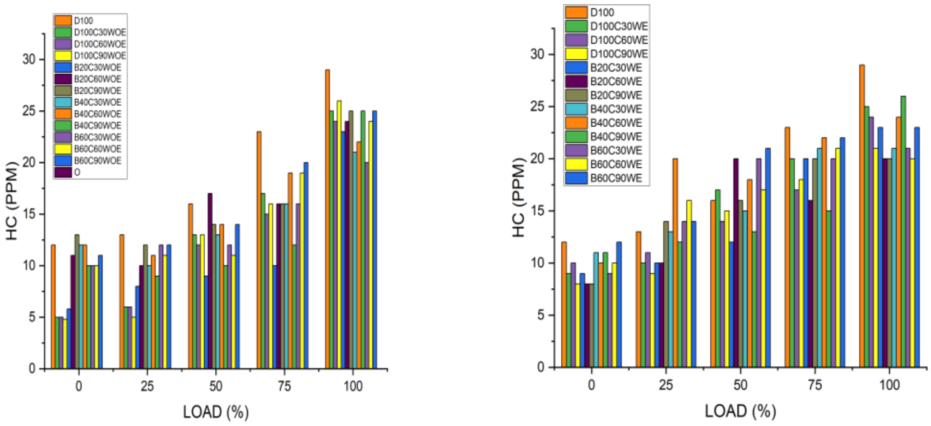


Figure 3 shows the variation of HC emission with respect to load for different fuel blends at (a) with EGR (b) without EGR

Figure 3 shows the emission of HC for the various blends. Adding different amounts of CeO2 nanoparticles to various fuels reduces hydrocarbon (HC) emissions. We are explicitly adding 30ppm, 60ppm and 90ppm of cerium oxide. Blend WE show an 11.53% reduction during the exact blend of 34.19 % without EGR at complete load condition. Reduction with the same blend is 4.34%, with EGR at 75% engine load. Blend B40C90 shows a 13.75 % reduction in HC with EGR and with the same blend 10.34 without EGR at full load.

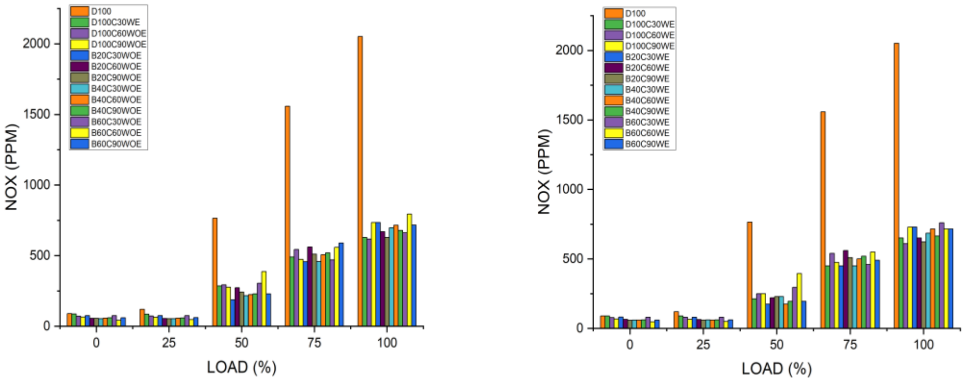


Figure 4 shows the variation of NOX emission with respect to load for different fuel blends at (a) with EGR (b) without EGR

NOx emissions are formed during combustion and depend on the time and fuel spent in the combustion chamber; extra oxygen presents a high combustion temperature. The variation in NOx emissions for different fuels is shown in Figure 4. The NOx emission from various blends and percentages of nanoparticles reduced the emission with EGR. The blend B20C90 has a 37.77% reduction in NOx without EGR and a 27.77% reduction with EGR at an ideal condition. Blend B20C90 has 54.19% without EGR and 50% with EGR reduction in NOx at 25% load. B40C30 86.07 % reduction in NOx without EGR while at 50% reduction in EGR. At 25% load. B60C30 reduces the 67.73% NOx without EGR and 62.96% reduction with EGR at full load condition.

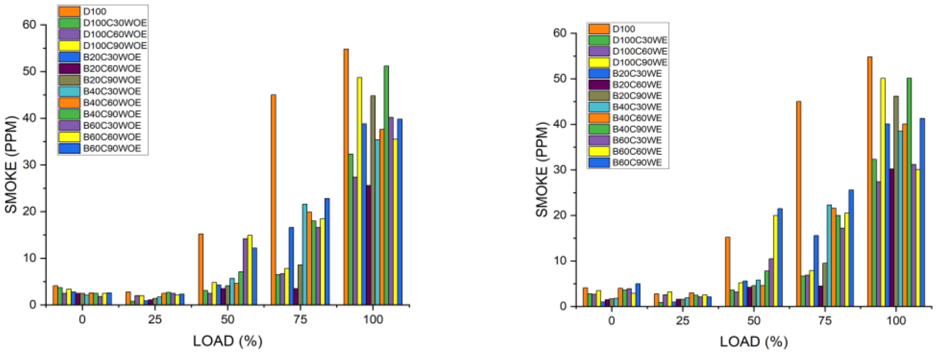


Figure 5 shows the variation of Smoke emission with respect to load for different fuel blends at (a) with EGR (b) without EGR

The smoke emission reduced with the additions of CeO2 nanoparticles get bonded during the combustion phase and lower the formation of soot; it also increases fuel combustion efficiency, promotes better combustion and reduces NOx emission was observed for test fuel at various proportions. B40C90 has a 6.56% reduction of NOx with EGR and a 6.54% reduction without EGR in full load conditions.

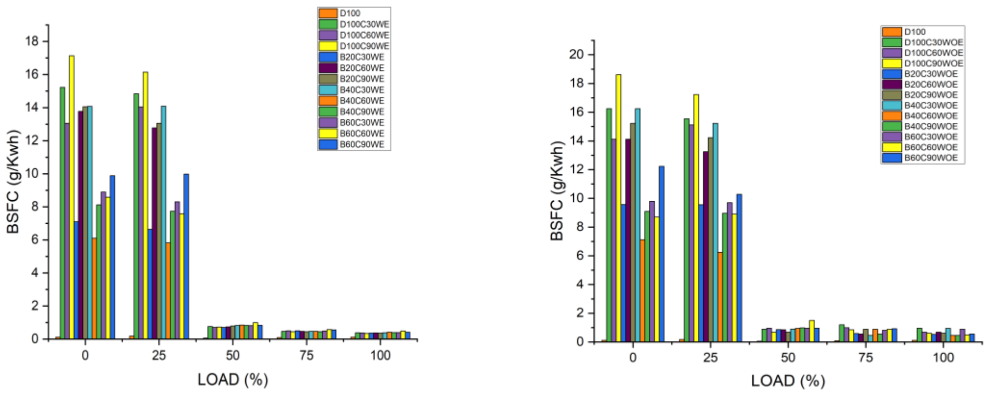


Figure 6 shows the variation of BSFC emission with respect to load for different fuel blends at (a) with EGR (b) without EGR

The difference in BSFC for tested fuels at various conditions is shown in Figure 6. BSFC from soybean biodiesel with cerium oxide nanoparticles is lesser than the diesel. Adding of 30, 60 and 90 ppm of nanoparticles resulted in 1.16%, 1.18%, 1.3%, 0.31%, 0.36%, 0.25%, 0.61% of B20C60, B20C90, B40C30, B40C90, B60C30, B60C60 and B60C90 respectively. Moreover, without EGR, it resulted in 0.28%, 0.85%, 1%, 1.14%, 0.02%, 0.24%, 0.01% and 0.42%. CeO2 nanoparticles complete combustion by giving off oxygen. (Pandian et al. 2017) CeO2 nanoparticles also help transfer heat between the fuel and air and mix fresh fuel with the burnt inside the combustion chamber (Devarajan et al.).The BSFC for tested fuels reduced at 20% of EGR. When using EGR, oxygen in the air decreases during combustion. They are leading to incomplete burning and poor combustion (Mahalingam et al 2018). Lower BSFC is observed because fuels have less oxygen content and burn at lower temperatures (yuvarajan et al. 2016).

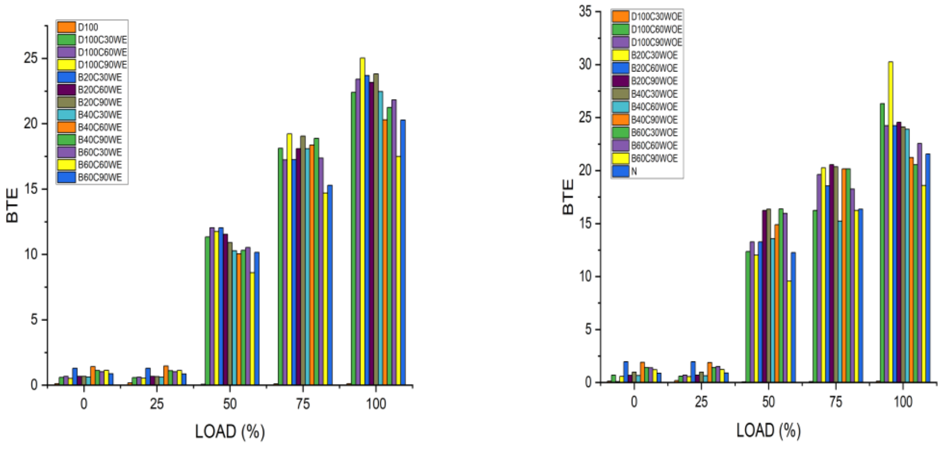


Figure 7 shows the variation of BTE emission with respect to load for different fuel blends at (a) with EGR (b) without EGR

The figure shows the variations of BTE for fuels, as shown in Figure 7. The BTE from soybean biodiesel and cerium oxide nanoparticles is less than that of pure diesel. Adding 30, 60, and 90 ppm of CeO2 nanoparticles into pure diesel resulted in 0.3% without EGR and 0.2% with EGR at all loads compared to neat diesel. A comparative fall in BTE was observed for tested fuel during 20% EGR.

5. CONCLUSION

This study examines adding CeO2 nanoparticles to a soybean biodiesel blend to find a CI engine's performance and emissions. The test was twelve different concentrations of CeO2 and diesel as D100C30, D100C60, D100C90 and B20C30, B20C60, B20C90 and B40C30, B40C60, B40C90 and B60C30, B60C60, B60C90 ppm. The engine used these blends at 0%, 25%, 50%, 75% and 100% load with 20% EGR and Without EGR. The findings on engine emissions are as follows: BTE increases, and BSFC reduces with increasing CeO2.CO HC emissions are low for EGR. NOx and smoke emissions drop with increasing CeO2 nanoparticle concentration.

REFERENCE

[1] S. Prakash, M. Prabhahar, and M. Saravana Kumar, “Experimental analysis of diesel engine behaviours using biodiesel with different exhaust gas recirculation rates,” *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 1508–1517, 2022, doi: 10.1080/01430750.2020.1712251.

[2] M. H. M. Yasin, R. Mamat, A. F. Yusop, P. Paruka, T. Yusaf, and G. Najafi, “Effects of Exhaust Gas Recirculation (EGR) on a Diesel Engine fuelled with Palm-biodiesel,” in *Energy Procedia*, Elsevier Ltd, 2015, pp. 30–36. doi: 10.1016/j.egypro.2015.07.131.

[3] A. F. Chen, M. A. Adzmi, and A. Adam, “Optimization evaluation of various type nanoparticles - diesel blended fuels on diesel engine combustion characteristics, performances and exhaust emissions,” *International Journal of Mechanical Engineering and Robotics Research*, vol. 9, no. 2, pp. 212–217, Feb. 2020, doi: 10.18178/ijmerr.9.2.212-217.

[4] krupakaran Radhakrishnan Lawrence, H. Tharigonda, and G. Alluru, “An experimental investigations on combined effect of EGR and SCR for diesel engine fuelled with the addition of TiO2 nanoparticle to M.Elangi methyl ester blend,” *Australian Journal of Mechanical Engineering*, vol. 18, no. 2, pp. 220–233, May 2020, doi: 10.1080/14484846.2018.1519053.

[5] A. Ahamad Shaik, S. Rami Reddy, V. Dhana Raju, and M. Govindarajan, “Combined influence of compression ratio and EGR on diverse characteristics of a research diesel engine fueled with waste mango seed biodiesel blend,” *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 2020, doi: 10.1080/15567036.2020.1811809.

[6] R. S. Kumar, M. Loganathan, and E. J. Gunasekaran, “Experimental investigation of the effect of simultaneous nitrogen, hydrogen and EGR addition in a biodiesel operated CI engine,” *Biofuels*, vol. 8, no. 6, pp. 685–692, Nov. 2017, doi: 10.1080/17597269.2016.1174017.

[7] A. Praveen, G. L. N. Rao, and B. Balakrishna, “The combined effect of multiwalled carbon nanotubes and exhaust gas recirculation on the performance and emission characteristics of a diesel engine,” *International Journal of Ambient Energy*, vol. 40, no. 8, pp. 791–799, Nov. 2019, doi: 10.1080/01430750.2017.1421576.

[8] Ö. Can, E. Öztürk, H. Solmaz, F. Aksoy, C. Çinar, and H. S. Yücesu, “Combined effects of soybean biodiesel fuel addition and EGR application on the combustion

and exhaust emissions in a diesel engine," *Appl Therm Eng*, vol. 95, pp. 115–124, Feb. 2016, doi: 10.1016/j.applthermaleng.2015.11.056.

[9] M. T. Chaichan, "Performance and emission characteristics of CIE using hydrogen, biodiesel, and massive EGR," *Int J Hydrogen Energy*, vol. 43, no. 10, pp. 5415–5435, Mar. 2018, doi: 10.1016/j.ijhydene.2017.09.072.

[10] C. Solaimuthu, V. Ganesan, D. Senthilkumar, and K. K. Ramasamy, "Emission reductions studies of a biodiesel engine using EGR and SCR for agriculture operations in developing countries," *Appl Energy*, vol. 138, pp. 91–98, Jan. 2015, doi: 10.1016/j.apenergy.2014.04.023.

[11] M. A. Fayad *et al.*, "Reducing Soot Nanoparticles and NOX Emissions in CRDI Diesel Engine by Incorporating TiO2 Nano-Additives into Biodiesel Blends and Using High Rate of EGR," *Energies (Basel)*, vol. 16, no. 9, May 2023, doi: 10.3390/en16093921.

[12] S. Manigandan, A. E. Atabani, V. K. Ponnusamy, A. Pugazhendhi, P. Gunasekar, and S. Prakash, "Effect of hydrogen and multiwall carbon nanotubes blends on combustion performance and emission of diesel engine using Taguchi approach," *Fuel*, vol. 276, Sep. 2020, doi: 10.1016/j.fuel.2020.118120.

[13] S. Manigandan, P. Gunasekar, S. Poorchilamban, S. Nithya, J. Devipriya, and G. Vasanthkumar, "Effect of addition of hydrogen and TiO2 in gasoline engine in various exhaust gas recirculation ratio," *Int J Hydrogen Energy*, vol. 44, no. 21, pp. 11205–11218, Apr. 2019, doi: 10.1016/j.ijhydene.2019.02.179.

[14] A. Praveen, G. Lakshmi Narayana Rao, and B. Balakrishna, "Performance and emission characteristics of a diesel engine using Calophyllum Inophyllum biodiesel blends with TiO2 nanoadditives and EGR," *Egyptian Journal of Petroleum*, vol. 27, no. 4, pp. 731–738, Dec. 2018, doi: 10.1016/j.ejpe.2017.10.008.

[15] R. Mobasheri, A. Aitouche, S. Pourtaghi Yousefdeh, and A. Zarenezhad Ashkezari, "Assessing the Impact of Ethanol/Biodiesel/Diesel Blends and Nanoparticle Fuel Additives on Performance and Emissions in a DI Diesel Engine with EGR Integration: An Experimental Study," *Processes*, vol. 11, no. 4, Apr. 2023, doi: 10.3390/pr11041266.

[16] P. Anchupogu, L. N. Rao, and B. Banavathu, "Effect of alumina nano additives into biodiesel-diesel blends on the combustion performance and emission characteristics of a diesel engine with exhaust gas recirculation," *Environmental Science and Pollution Research*, vol. 25, no. 23, pp. 23294–23306, Aug. 2018, doi: 10.1007/s11356-018-2366-7.

[17] V. Rajasekar, V. E. Geo, L. J. Martin, and B. Nagalingam, "The combined effect of low viscous biofuel and EGR on NO-smoke tradeoff in a biodiesel engine—an experimental study," *Environmental Science and Pollution Research*, vol. 27, no. 15, pp. 17468–17480, May 2020, doi: 10.1007/s11356-019-05449-8.

[18] R. Sathiyamoorthi, G. Sankaranarayanan, and K. Pitchandi, "Combined effect of nanoemulsion and EGR on combustion and emission characteristics of neat lemongrass oil (LGO)-DEE-diesel blend fuelled diesel engine," *Appl Therm Eng*, vol. 112, pp. 1421–1432, Feb. 2017, doi: 10.1016/j.applthermaleng.2016.10.179.

[19] Z. Tan, J. Wang, W. Chen, L. Shen, and Y. Bi, "Study on the influence of egr on the combustion performance of biofuel diesel at different ambient simulated pressures," *Sustainability (Switzerland)*, vol. 13, no. 14, Jul. 2021, doi: 10.3390/su13147862.

[20] H. Venu, L. Subramani, and V. D. Raju, "Emission reduction in a DI diesel engine using exhaust gas recirculation (EGR) of palm biodiesel blended with TiO2 nano

additives," *Renew Energy*, vol. 140, pp. 245–263, Sep. 2019, doi: 10.1016/j.renene.2019.03.078.

[21] V. Veerabadran, M. Veerasigamani, and S. Shanmugam, "Effect of carbon nanotube material in diesel engine with exhaust gas recirculation," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, 2020, doi: 10.1080/15567036.2020.1729901.

[22] R. Selvabharathi, M. Selvam, and S. K. Palani, "Investigation of performance, combustion, and emission characteristics of diesel engine equipped with exhaust gas recirculation using ceria and zirconia nanoparticles-blended rice bran biodiesel," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, vol. 44, no. 2, pp. 5508–5526, 2022, doi: 10.1080/15567036.2020.1829193.

[23] M. A. Fayad *et al.*, "Incorporating of TiO2 with oxygenated fuel and post-injection strategy in CRDI diesel engine equipped with EGR: A step towards lower NOX, PM and enhance soot oxidation reactivity," *Case Studies in Thermal Engineering*, vol. 53, Jan. 2024, doi: 10.1016/j.csite.2023.103894.

[24] V. Saxena, N. Kumar, and V. K. Saxena, "Multi-objective optimization of modified nanofluid fuel blends at different TiO2 nanoparticle concentration in diesel engine: Experimental assessment and modeling," *Appl Energy*, vol. 248, pp. 330–353, Aug. 2019, doi: 10.1016/j.apenergy.2019.04.091.

[25] R. Hussain Vali *et al.*, "Optimization of variable compression ratio diesel engine fueled with Zinc oxide nanoparticles and biodiesel emulsion using response surface methodology," *Fuel*, vol. 323, Sep. 2022, doi: 10.1016/j.fuel.2022.124290.

[26] C. Srinidhi, A. Madhusudhan, and S. V. Channapattana, "Comparative analysis of exhaust gas recirculation and nanoparticles on the performance and emission of diesel engine fuelled with Neem biodiesel blend," *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 290–299, 2022, doi: 10.1080/01430750.2019.1636876.

[27] V. Manieniyan, V. Sukumar, R. Senthilkumar, and S. Sivaprakasam, "Emission reduction using biodiesel blends with nano-additives and reformed exhaust gas recirculation (REGR) in DI diesel engine," *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 641–647, 2022, doi: 10.1080/01430750.2019.1662842.

[28] G. Ramakrishnan, P. Krishnan, S. Rathinam, R. Thiyagu, and Y. Devarajan, "Role of nano-additive blended biodiesel on emission characteristics of the research diesel engine," *Int J Green Energy*, vol. 16, no. 6, pp. 435–441, May 2019, doi: 10.1080/15435075.2019.1577742.

[29] S. Ganesan, T. Arunkumar, D. Munuswamy, P. Appavu, and Y. Devarajan, "Effect of egr & nanoparticles on performance and emission characteristics of a diesel engine fuelled with palm biodiesel and diesel blends," *J Oil Palm Res*, vol. 31, no. 1, pp. 130–137, 2019, doi: 10.21894/fjopr.2018.0065.