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EFFECT OF INJECTION TIMING ON PERFORMANCE AND EMISSION CHARACTERISTICS OF PALM BIODIESEL AND DIESEL BLENDS

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ABSTRACT

Injection timing is a vital factor which governs the emissions and performance characteristics of the engine. This work portrays the effect of injection timing (IT) on cerium oxide nano particle doped palm biodiesel (20%vol) and diesel (80%vol) blends. Palm biodiesel is found to be a promising alternative to the petroleum diesel fuel owing to their similarity in physical and chemical properties. Addition of cerium oxide nano particle is carried out at 30 ppm, 60 ppm and 90 ppm. The modified fuels are introduced in reducing injection timing of 19°, 21° and 23° bTDC. A four-stroke, vertical, air-cooled, single cylinder, diesel engine is employed in this study. The performance characteristics (BSFC, BTE) improved for fuel blends at IT=23° bTDC. Further, results also revealed a significant reduction in emissions CO, $NO_{X,}$ HC emissions at IT=23° bTDC.

Keywords: palm biodiesel, cerium oxide nano particle, performance, exhaust emissions.

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INTRODUCTION

Increasing energy demand and restructured emission norms pave the way the search for a promising alternative such as biofuels for engine applications. By utilising biofuels, the gap between demand and energy source is reduced significantly (Devarajan *et al*., 2016). Biodiesels are biodegradable, readily available, portable, and renewable in nature (Devarajan *et al*., 2017a). Biodiesel is obtained from a variety of natural feedstock sources providing possible starting materials for biodiesel production (Devarajan *et al*., 2017b). A variety of non-edible seeds such as neem, jatropha, pongamia, mahua, and castor are employed to obtain the biodiesel. Non-edible oil plants are distinguished from a second-generation feedstock which is economical and is cultivated across the globe. Vegetable oils require a chemical process called transesterification to reduce its fatty acid contents (Murugesan *et al*., 2013). After transesterification, vegetable oils can be blended with diesel or can also be used as a neat fuel in diesel with no or minor modifications.

Many research works have found that appending nano-sized metallic particle at different proportions to biodiesel can reduce its emissions (Pandian *et al*., 2017). The CeO_2, NiO, MnO, ZnO and CuO have commonly used metal oxides. Metal oxide nanoparticle improves the rate of evaporation of fuels, reduces the delay period and lowers the emissions of biodiesel. Pandian *et al*. (2017) scrutinised the impact of TiO_2 nano metals and reported significant improvement in its chemical properties. In addition, 4% of NO_x emissions were reduced below that of diesel. Sajeevan *et al*. (2016) reviewed the effects of nano metals as an additive in biodiesel-fueled engines. They reported that nano

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metal acts as an oxidation buffer and reduces the NO_x emissions in the range between 2.1% and 6.7%. Ravichandra Ganesh and Hemachandra Reddy (2015) scrutinised the emission impact of CeO_2 in biodiesel. They found that by incorporating of CeO_2 in neat biodiesel, NO_x emissions were reduced by 3.7% and 4.4%, respectively. From the survey of the literature, it has been experimentally found that by appending metal oxide nano particle to diesel and biodiesel blends, the NO_X emissions are reduced and the combustion improves. Hence, this work aims to investigate the effect of appending CeO_2 nano particle in the powder form at 30, 60 and 90 ppm to palm biodiesel and diesel blends. In addition, the effect of injection timing (IT) on the cerium oxide nano particle doped palm biodiesel (20%vol) and diesel (80%vol) blends (BD20) is also investigated and compared with diesel.

MATERIALS AND METHODS

Preparation of Palm Biodiesel

Palm oil biodiesel was extracted from the neat palm oil through the alkali-based transesterification process. A solution containing 47.5 ml of methanol and 2.5 ml of catalysts (sodium hydroxide) is mixed with 600 ml of palm oil. The mixture is heated to 80°C for 60 min at constant agitation. The mixture was then undisturbed to obtain neat biodiesel and methanol. The methanol in the mixture was then removed by reheating 90°C. Cerium oxide nano particles in the nano powder form (CeO_2, alpha, 98+%, 50 nm) were mixed with BD20 at different dosage levels of 30, 60 and 90 ppm by mass basis. *Table 1* shows the properties of cerium oxide nano particles. Ultrasonicator with a frequency of 60-100 kHz is employed to ensure a homogenous emulsion.

TABLE 1. PROPERTIES OF CERIUM OXIDE NANO PARTICLES

Molecular formula	CeO_2
Molecular weight	81.12 g mol^{-1}
Average particle size	60 nm
Form	Powder
Colour	Pure white

Fuel containing CeO_2 nano particle is further mixed and stirred with surfactant (Span-80) using a magnetic agitator for 60 min at a speed of 510 rpm in atmospheric conditions to improve the bonding between nanoparticle and fuel. *Table 2* shows the properties of the modified fuels and diesel.

Experimental Set-up

Research type 4.4 kW immobile engine (compression ratio = 16.5:1; speed = 1600 rpm; cylinder = 1) fuelling the biodiesel (methyl ester) is employed in this work. *Table 3* shows the specification of the engine. Eddy current dynamometer is used in the work. The schematic layout of engine set-up is shown in *Figure 1*. The engine exhausts are measured by AVL Ditest gas 1000 exhaust gas analyser. Chromel K-Type thermocouple was used for measuring the exhaust gas temperature.

RESULTS AND DISCUSSION

The analysis is carried out with diesel, BD20 and nano particle additive to BD20 in 30 ppm, 60 ppm and 90 ppm and injected at 23° bTDC and 200 bar. Modified biodiesels are injected into the engine at 240 bar pressure and the IT is varied between 19° and 21° bTDC for comparison.

Brake Thermal Efficiency (BTE)

Figures 2a, 2b and *2c* show the variations in BTE for palm biodiesel and diesel blends (BD20) doped with different proportions of CeO_2 nanoparticles. BTE of the biodiesel is less than diesel at all loads (Murugesan *et al*., 2013). This is due to the higher calorific value of diesel. BTE of test fuels increases with the load. At higher loads, conversion of fuel into useful work is higher causing higher BTE. In addition, CeO_2 nano particle improved BTE of tested fuels. The CeO_2 buffers oxygen and improve BTE (Naik and Balakrishna, 2017; Pandian *et al*., 2017). This is due to the catalytic activity of CeO_2 nano particle which aids the improved combustion (Pandian *et al*., 2017). Further, the CeO_2 nano particle provides surplus oxygen during combustion which in turn promotes the oxidation reaction

TABLE 2. PROPERTIES OF THE PALM BIODIESEL AND DIESEL BLENDS

	Diesel	BD20	BD20+30 ppm	BD20+60 ppm	BD20+90 ppm
Kinematic viscosity @40°C in cSt	2.4	3.47	3.58	3.83	3.97
Flash point (°C)	46	49	52	63	75
Fire point (°C)	55	60	65	76	87
Calorific value (kJ kg^{-1})	42 534	41 342	41 402	41 514	41 608
Density @15°C in kg m^{-3}	835	858	862	865	869

TABLE 3. SPECIFICATION OF THE ENGINE

1. Type	2. Four stroke
3. Stroke	4. 110 mm
5. Bore	6. 88 mm
7. Rated output	8. 4.4 kW
9. Rated speed	10. 1600 rpm
11. Injection timing (°bTDC)	12. 19 - 23
13. Compression ratio	14. 16.5
15. Loading device	16. Electric generator
17. Injection pressure	18. 200 bar
19. Fuel pump plunger diameter	20. 8 mm
21. Number of injector nozzle	22. 4
23. Diameter of injector nozzle	24. 0.32 mm
25. Cooling	26. Air cooled
27. Position	28. Vertical
29. Dynamometer constant	30. 2000
31. Supply voltage	32. 240±10 % AC,50 Hz, 1Φ
33. Maximum excitation current	34. 6 to 8 Amp

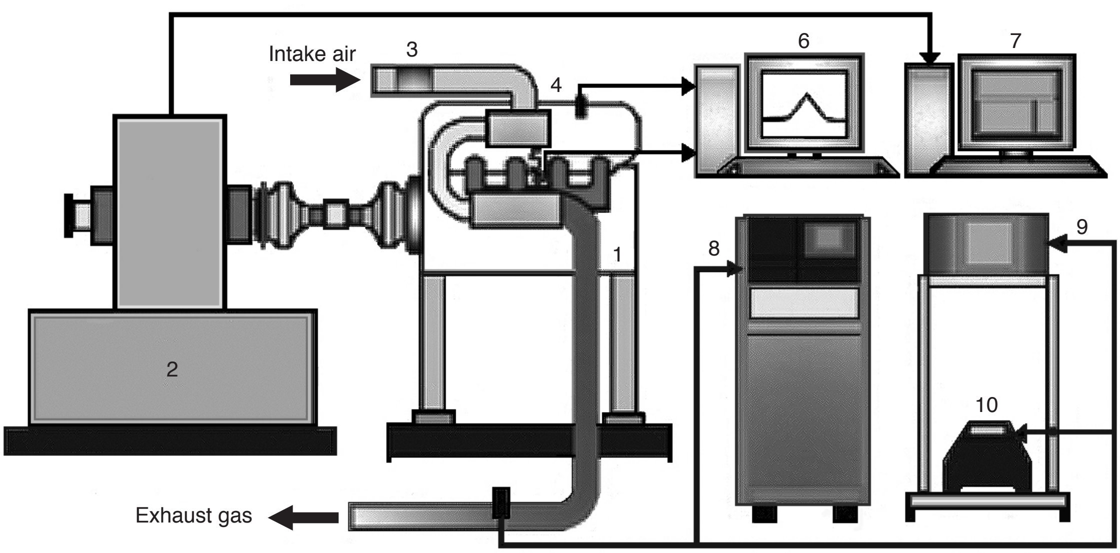
(Pandian *et al*., 2017). Significant improvement in BTE is observed at 23°CA bTDC. At retard IT (23°CA bTDC), there is the lesser quantity of fuel admittance which improves the atomisation process and combustion process and results in higher BTE. This result is in line with much other research works carried for nano particle additives with biodiesel (Sabari *et al*., 2018; Karthikeyan and Jayaprabakar, 2017). At full load conditions, BTE for biodiesel and diesel blends are lower than diesel. However, by adding CeO_2 nano particle at 30 ppm, 60 ppm and 90 ppm, a marginal increase in BTE are observed for biodiesel and diesel blends.

Brake Specific Fuel Consumption (BSFC)

Figures 3a, *3b* and *3c* show the variations in BSFC for palm biodiesel and diesel blends (BD20) doped with different proportions of CeO_2 nano particles. BSFC of the biodiesel and diesel blends is more than diesel at all loads (Raj Bukkarapu *et al*., 2017). BSFC of test fuels decreases with the load. In addition, CeO_2 nano particle improved BSFC for biodiesel and diesel blends. The CeO_2 nano particle buffers oxygen and improve BSFC (Pandian *et al*., 2017). Significant reduction in BSFC is observed at 23° CA bTDC. At retard IT (23° CA bTDC), there is the lesser quantity of fuel admittance which improves the atomisation process and combustion process and results in lower BSFC. At full load conditions, BSFC for biodiesel and diesel blends is higher than diesel. However, by adding CeO_2 nano particle at 30 ppm, 60 ppm and 90 ppm, a marginal decrease in BSFC are observed for biodiesel and diesel blends. This result is in line with much other research works carried for nano particle additives with biodiesel (Jayaprabakar *et al*., 2015; Sabari *et al*., 2018).

Unburned Hydrocarbon (HC) Emissions

Figures 4a, *4b*, and *4c* show the variations in HC emission for palm biodiesel and diesel blends (BD20) doped with different proportions of CeO_2 nano particles. HC emissions from biodiesel and diesel blends are less than diesel at all loads (Venkata Ramanan and Yuvarajan, 2016). HC emissions for



1. Test engine
2. Eddy current dynamometer
3. Air mass sensor
4. Pressure sensor
5. Accelerometer
6. Data aquisition system (DAS)
7. Dynamometer controller
8. Bosch gas analyser
9. AVL digas analyser
10. Smoke opacity meter

Figure 1. The schematic layout of engine set-up.

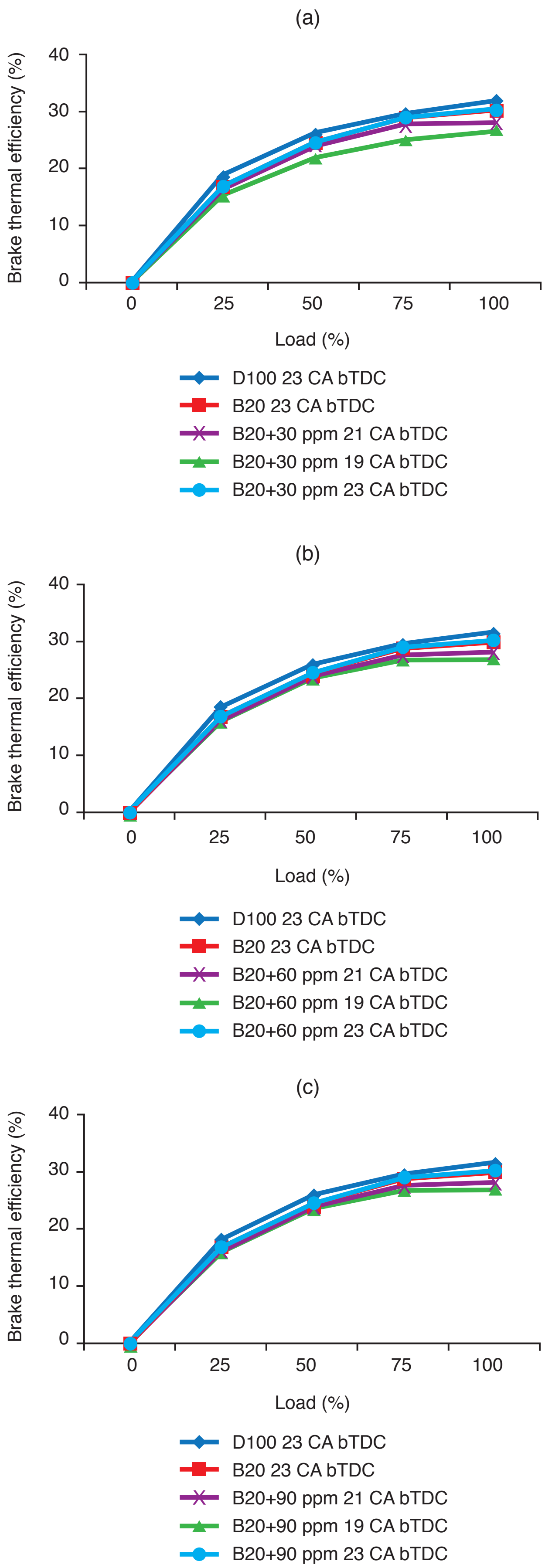


Figure 2. Brake thermal efficiency (BTE) of palm biodiesel and diesel blends at different working conditions (a, b, c).

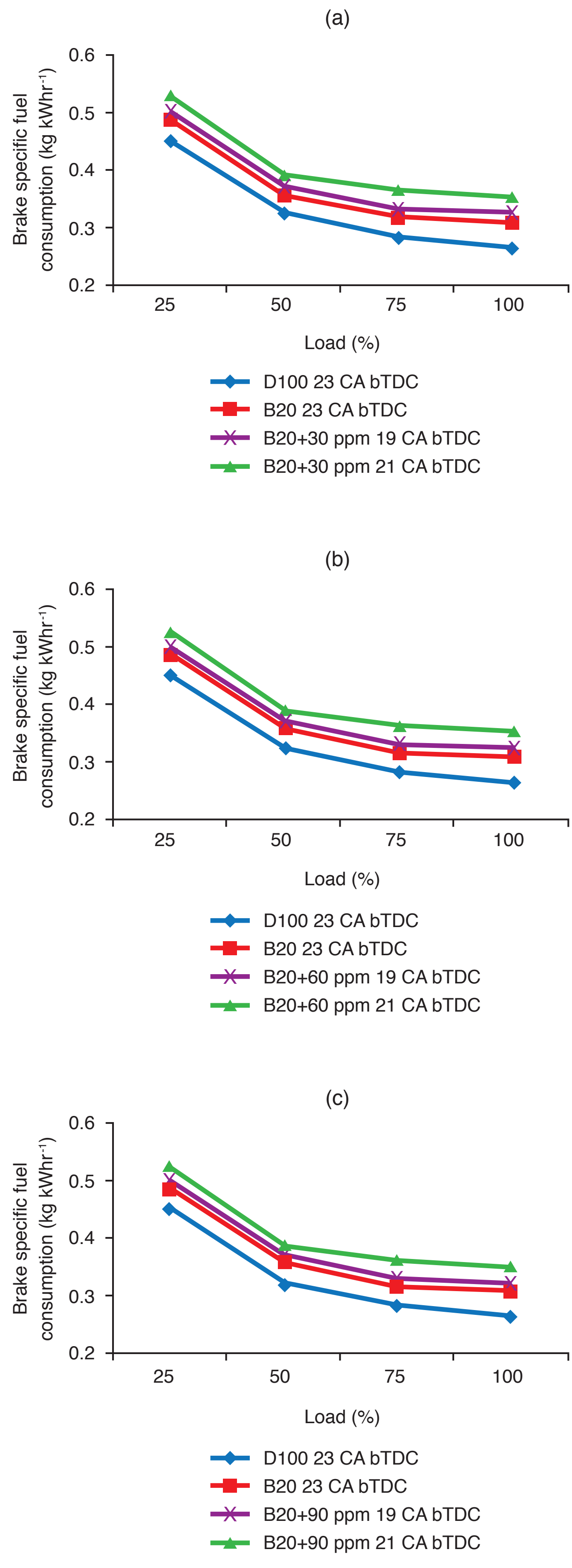


Figure 3. Brake specific fuel consumption (BSFC) of palm biodiesel and diesel blends at different working conditions (a, b, c).

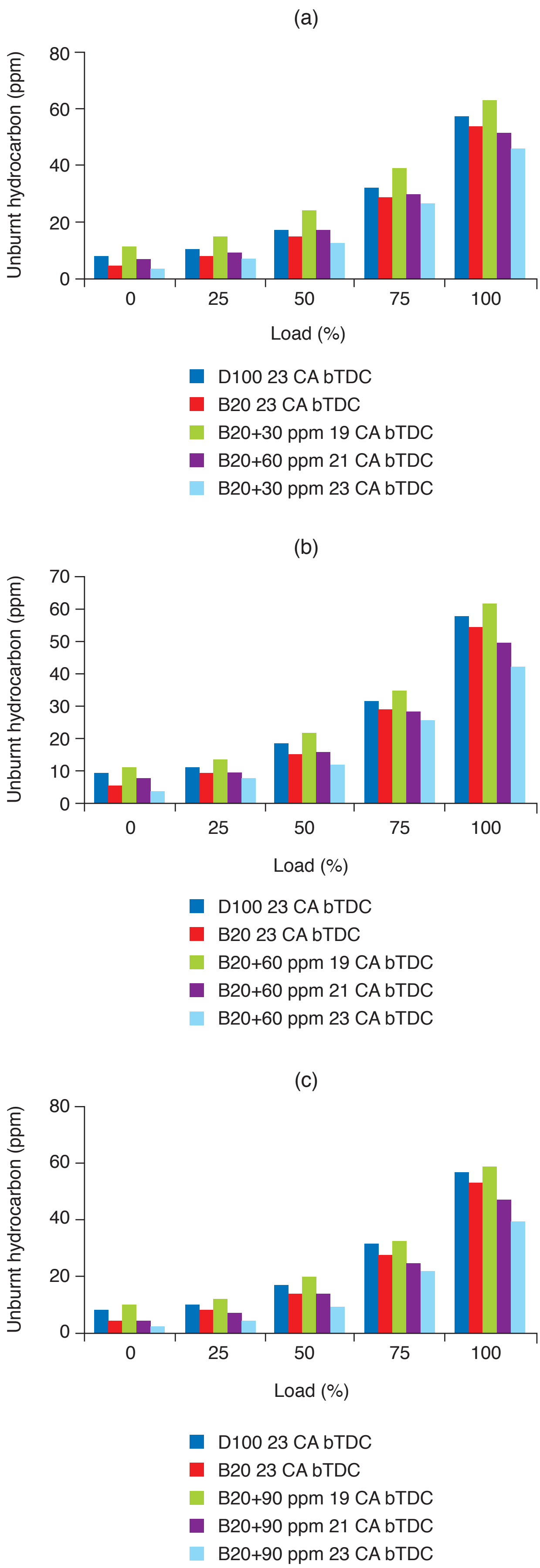


Figure 4. Hydrocarbon (HC) emissions of palm biodiesel and diesel blends at different working conditions (a, b, c).

all fuels increase with the load. At higher loads, the mixture becomes too rich causing higher HC emissions. Addition of CeO_2 nano particle improved the combustion of fuels by supplying additional oxygen during combustion (Ravichandra Ganesh and Hemachandra Reddy, 2015). The 15% to 26% reduction in HC is observed by adding CeO_2 nano particle to tested fuels at 23° bTDC. The CeO_2 acts as an oxidation catalyst and enhance the HC and provides the complete combustion. In addition, a significant reduction in HC emissions is observed at 23°CA bTDC. At retard IT (23°CA bTDC), there is the lesser quantity of fuel admittance which improves the atomisation process and combustion process and results in lower HC emissions. This result is in line with much other research works carried for nano particle additives with biodiesel (Jayaprabakar *et al*., 2015; Sabari *et al*., 2018).

Carbon Monoxide (CO) Emission

Figures 5a, 5b and *5c* show the variations in CO emission for palm biodiesel and diesel blends (BD20) doped with different proportions of CeO_2 nano particles. The CO emissions from biodiesel and diesel blends are less than diesel at all loads (Venkata Ramanan and Yuvarajan, 2016). The CO emissions from all fuels increase with the load. At higher loads, the mixture becomes too rich causing higher CO emissions. Addition of CeO_2 nano particle reduces CO emissions for tested fuels. This is due to the catalytic activity of CeO_2 nano particle which aids the improved combustion. Further, the CeO_2 nano particle provides surplus oxygen during combustion which in turn promotes the oxidation reaction (Ravichandra Ganesh and Hemachandra Reddy, 2015; Pandian *et al*., 2017). The 14% to 22% reduction in CO is observed for adding CeO_2 (30 ppm to 90 ppm) to tested fuels at 23° bTDC. At retard IT (23° CA bTDC), there is the lesser quantity of fuel admittance which improves the atomisation process and combustion process and results in lower CO emissions. This result is in line with much other research works carried for nano particle additives with biodiesel (Jayaprabakar *et al*., 2015; Sabari *et al*., 2018; Venkata Ramanan and Yuvarajan, 2016).

Nitrogen Oxides (NO_X) Emission

Figures 6a, 6b and *6c* show the variations in NO_X emissions for palm biodiesel and diesel blends (BD20) doped with different proportions of CeO_2 nano particles. The NO_X formation is attributed to three main factors namely, high combustion temperature, the presence of an excess of oxygen and the chemical kinetic rate. The NO_X for BD20 is higher than diesel at all loads owing to the higher inbuilt oxygen content in fuel and high temperature during combustion

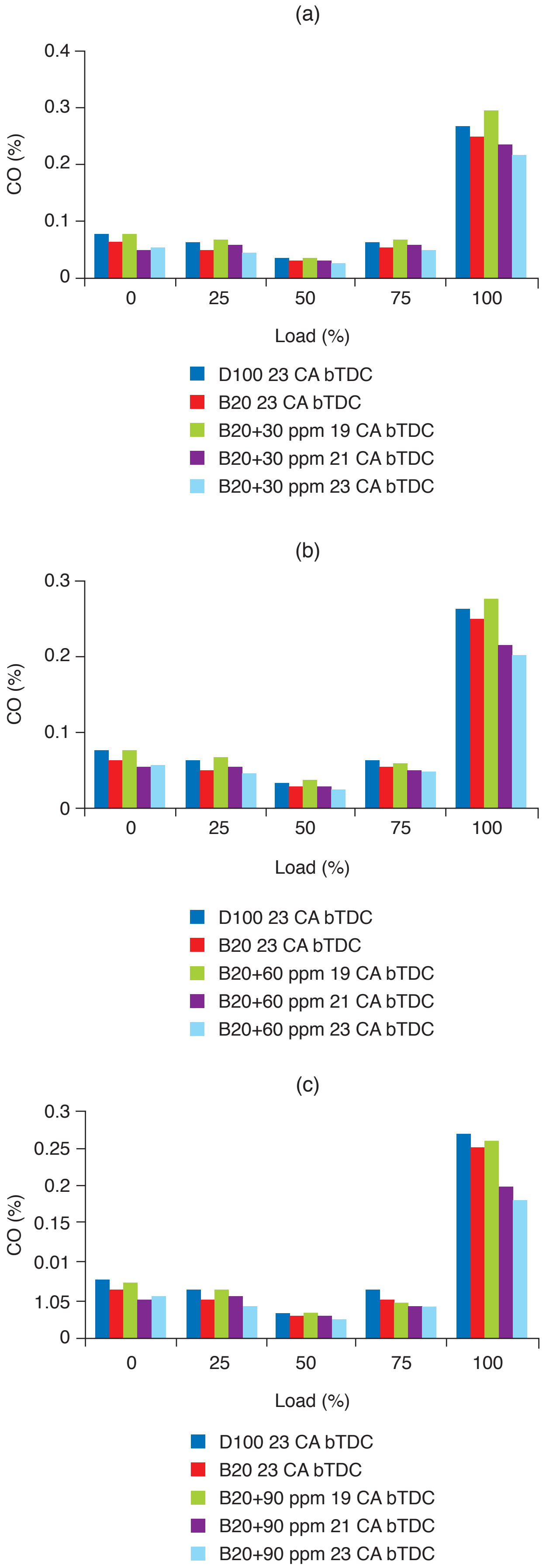


Figure 5. Carbon monoxide (CO) emissions of palm biodiesel and diesel blends at different working conditions (a, b, c).

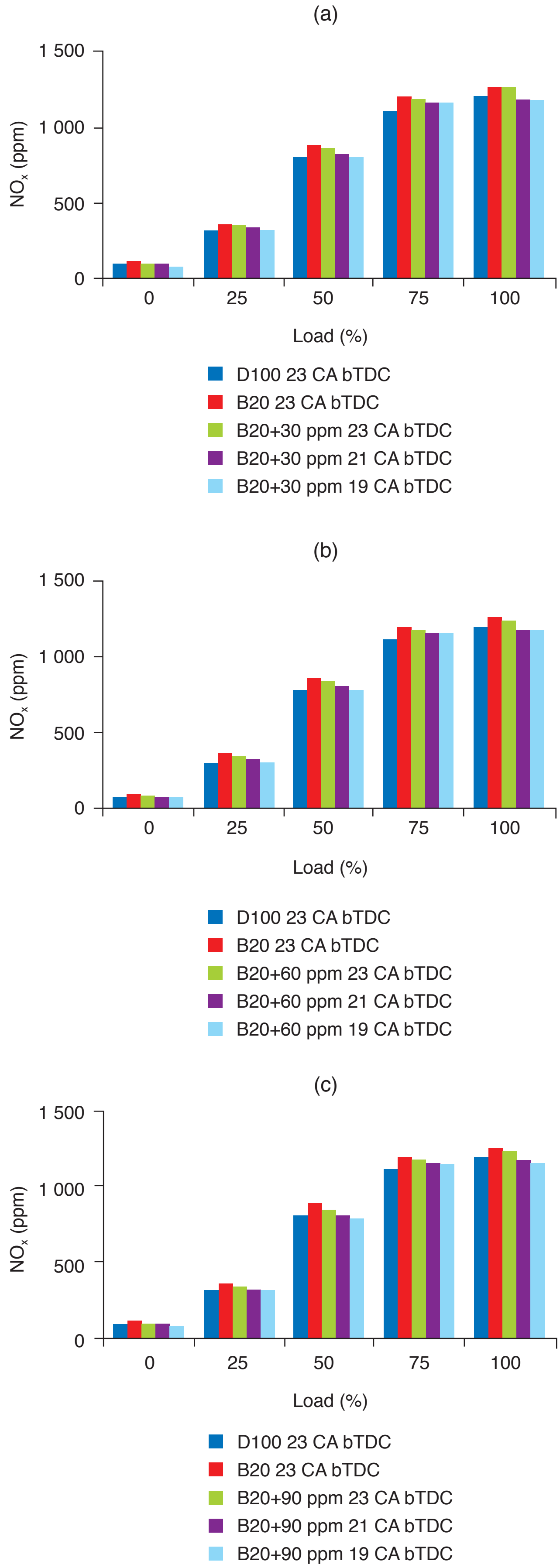


Figure 6. The nitrogen oxide (NO_X) emissions of palm biodiesel and diesel blends at different working conditions (a, b and c).

inside the combustion chamber (Yuvarajan *et al*., 2017; Sabari *et al*., 2018; Jayaprabakar *et al*., 2017). The NO_X emissions for tested fuels increase with the load. At higher loads, the temperature during combustion becomes higher causing higher NO_X emissions. The addition of CeO_2 nano particle reduces NO_X emissions for tested fuels. This is due to the catalytic activity of CeO_2 nano particle which aids the improved combustion. Further, the CeO_2 nano particle provides surplus oxygen during combustion which in turn promotes the oxidation reaction (Ravichandra Ganesh and Hemachandra Reddy, 2015; Pandian *et al*., 2017). The CeO_2 nano particle increases the effective surface area due to inbuilt oxygen and accelerates the oxidation reaction and lower NO_x emission. This result is in line with much other research works carried for nano particle additives with biodiesel (Ravichandra Ganesh and Hemachandra Reddy, 2015; Pandian *et al*., 2017). The 8% to 12% reduction in NO_x is observed for adding CeO_2 (30 ppm to 90 ppm) to BD20 at 23° bTDC. At retard IT (23°CA bTDC), there is the lesser quantity of fuel admittance which improves the atomisation process and combustion process and results in lower combustion temperature and lowers NO_X emissions. This result is in line with much other research works carried for nano particle additives with biodiesel (Jayaprabakar *et al*., 2015; Sabari *et al*., 2018; Venkata Ramanan and Yuvarajan, 2016).

CONCLUSION

The intention of this experimental work is to observe the effect of IT (19°, 21° and 23°) on cerium oxide nano particle doped palm biodiesel and diesel blends. A four-stroke, vertical, air-cooled, single cylinder, diesel engine is operated using test fuels. The results obtained are compared with petroleum diesel and the major conclusions drawn from this work is detailed as follows;

- palm biodiesel can be blended with diesel;
- CeO_2 nano particle doped palm biodiesel and diesel blends showed better-quality performance than neat blends;
- HC and CO emissions for palm biodiesel and diesel blends are lesser than diesel at all working conditions owing to its oxidation capability and the catalytic effect; and
- NO_X emissions for palm biodiesel and diesel blends are higher than diesel at all working conditions. However, NO_X emissions decreased with retard IT (IT=23°bTDC).

REFERENCES

DEVARAJAN, Y; JAYABAL, R KUMAR; RAGUPATHY, D and VENU, H (2016). Emissions analysis on second generation biodiesel. *Frontiers Environ. Sci. Eng*., *11(1)*: 3.

DEVARAJAN, Y; NAGAPPAN, B K and MUNUSWAMY, D B (2017a). Performance and emissions analysis on diesel engine fuelled with cashew nut shell biodiesel and pentanol blends. *Korean J. Chem. Eng*., *344*: 1021-1026.

DEVARAJAN, Y; MUNUSWAMY, D B and MAHALINGAM, A (2017b). Performance, combustion and emission analysis on the effect of ferrofluid on neat biodiesel. *Process Saf. Environ. Prot*., *111*: 283-291.

JAYAPRABAKAR, J; DEY, B; DEY, K; HAREESH, B and ANISH, M (2017). Optimization of rice bran biodiesel blends on CI engine and investigating its effects. *IOP Conference Series: Materials Science and Engineering, 197*: 012016. DOI:10.1088/1757-899x/197/1/012016.

JAYAPRABAKAR, J; KARTHIKEYAN, A and RAMESHKUMAR V (2015). Effect of injection timing on the combustion characteristics of rice bran and algae biodiesel blends in a compression-ignition engine. *I. J. Ambient Energy, 38(2)*: 116-121. DOI:10.1080/01430750.2015.1048901.

KARTHIKEYAN, A and JAYAPRABAKAR, J (2017). Energy and exergy analysis of compression ignition engine fuelled with rice bran biodiesel blends. *I. J. Ambient Energy*: 1-7. DOI:10.1080/01430750.2017.13 99459.

MURUGESAN, A; SUBRAMANIAM, D; AVINASH, A and NEDUNCHEZHIAN, N (2013). Quantitative and qualitative analysis of biodiesel - An in-depth study. *I. J. Ambient Energy*, *36(1)*: 19-30.

NAIK, N S and BALAKRISHNA, B (2017). A comparative study of B10 biodiesel blends and its performance and combustion characteristics. *I. J. Ambient Energy*: 257-263. DOI:10.1080/01430750.20 17.1303629.

PANDIAN, A K; RAMAKRISHNAN, R B B; and DEVARAJAN, Y (2017). Emission analysis on the effect of nanoparticles on neat biodiesel in unmodified diesel engine. *Envi. Science Pollution Res*, *24(29)*: 23273-23278. DOI:10.1007/s11356-017-9973-6.

RAJ BUKKARAPU, K (2017). Comparative study of different biodiesel–diesel blends. *I. J. Ambient Energy*: 1-9. DOI:10.1080/01430750.2017.1393775.

RAVICHANDRA GANESH, P and HEMACHANDRA REDDY, K (2015). Experimental investigation on the performance and emission characteristics of di-diesel engine using diesel-ethanol blends with aqueous cerium oxide nanofluid as additive. *Appl Mech. Mater. 787*: 741-745. DOI:10.4028/www.scientific.net/amm.787.741.

SABARI GIRISH, G; VIJAYAKOTHANDARAMAN, R and PRABHU, A (2018). Experimental investigation on a CI engine fuelled with bio gas and rice straw additives. *I. J. Ambient Energy*: 1-3. DOI:10.1080/01430750.2017.1423388.

SAJEEVAN, A C and SAJITH, V (2016). Synthesis of stable cerium zirconium oxide nanoparticle – Diesel suspension and investigation of its effects on diesel properties and smoke. *Fuel, 183*: 155-163. DOI:10.1016/j.fuel.2016.06.048.

VENKATA RAMANAN, M and YUVARAJAN, D (2016). Emission analysis on the influence of magnetite nanofluid on methyl ester in diesel engine. *Atmos. Pollu. Res*, *7(3)*: 477-481. DOI:10.1016/j.apr.2015.12.001.

YILMAZ, N and ATMANLI, A 2017. Experimental assessment of a diesel engine fueled with diesel-biodiesel-1-pentanol blends. *Fuel, 191*: 190-197.

YUVARAJAN, D; DINESH BABU, M; BEEMKUMAR, N and AMITH KISHORE, P (2017). Experimental investigation on the influence of titanium dioxide nanofluid on emission pattern of biodiesel in a diesel engine. *Atmos Pollu Res*., *9(1)*: 47 – 52. DOI:10.1016/j.apr.2017.06.003.

YUVARAJAN, D; RAVIKUMAR, J and BABU, M D (2016). Simultaneous optimization of smoke and NOx emissions in a stationary diesel engine fuelled with diesel-oxygenate blends using the grey relational analysis in the Taguchi method. *Anal. Methods*, *832*: 6222-6230.