Journal of Oil Palm Research Vol. 31 (1) March 2019 p. 130-137
DOI: https://doi.org/10.21894/jopr.2018.0065

EFFECT OF EGR & NANOPARTICLES ON PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE FUELLED WITH PALM BIODIESEL AND DIESEL BLENDS

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ABSTRACT

This work examines the consequence of employing cerium oxide (CeO_2) nanoparticles at a different proportion (30 ppm, 60 ppm and 90 ppm) to palm oil methyl ester and diesel blends (B20) in water-cooled single cylinder four stroke diesel engine. Adding nanoparticles is a strategy to improve the performance and reduce emissions of the biodiesel. Prepared samples are fuelled to diesel engine by admitting exhaust gas recirculation (EGR) of 10% and 20% by volume. The main intention of this study is to lessen the nitrogen oxide (NO_X) emissions for diesel and biodiesel blends. Experimental results found a significant reduction NO_X, carbon monoxide (CO), smoke and hydrocarbon (HC) emissions at 10% EGR rate. However, brake specific fuel consumption is increased with significant lower brake thermal efficiency by admitting EGR of 20% by volume. Thus, it can be inferred that EGR of 10% by volume is an optimal way on reducing harmful emissions without compromising much on performance aspects of biodiesel fuelled diesel engine.

Keywords: palm biodiesel, exhaust gas recirculation, engine.

Date received: 8 March 2018; **Sent for revision:** 6 April 2018; **Received in final form:** 17 May 2018; **Accepted:** 18 December 2018.

INTRODUCTION

The fuel and energy crisis of the late 2000 and early 2010 as well as accompanying concerns about the depletion of the world's non-renewable resources provided the incentives to seek alternatives to conventional, petroleum-based fuels. As the world reserves of fossil fuels and raw materials are limited, active research interest has been stimulated in non-petroleum, renewable, and non-polluting fuels. Biofuels are the only alternative energy sources for the foreseeable future and can still form the basis of sustainable development in terms of socio-economic and environmental concerns (Devarajan *et al.*, 2016). In this context, vegetable oils as fuel for diesel engines are considered. They now occupy a prominent position in the development of alternative fuels. Worldwide vegetable oils are used in compression ignition (CI) engines either as a sole fuel or blended with diesel fuel (Jayaprabakar and Karthikeyan, 2016; Pandian *et al.*, 2017).

Many studies have attempted to decrease the nitrogen oxide (NO_X) emissions from a biodiesel-fuelled diesel engine. Devarajan *et al.* (2016) carried

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out an investigation on a content speed single cylinder diesel engine fuelled with neat biodiesel by adding 2% ferrofluid as an oxygenated additive. They resulted in 2.7% increase in NO_X emission. Yuvarajan *et al.* (2016) investigated the effect of varying the compression ratio in neat biodiesel fuelled diesel engine. They found that an increase in compression ratio improved the performance aspects with a significant reduction in smoke, carbon monoxide (CO) and hydrocarbon (HC) emissions. However, NO_X emissions found to increase with an increase in compression ratio. Ravikumar and Saravanan (2016) carried out an investigation on a content speed single cylinder diesel engine fuelled with neat yellow grease derived biodiesel by adding 20% pentanol as an oxygenated additive. They resulted in a 1.6% increase in NO_X emission by adding pentanol to yellow grease derived biodiesel.

Many investigations were attempted to decrease the NO_X emissions from biodiesel and diesel blends fuelled diesel engine. Anbarasu and Karthikeyan (2015) performed an experimental study on biodiesel and diesel with the addition of aluminium oxide nanoparticle in direct injection constant speed diesel engine. Aluminium oxide nanoparticle at 250 ppm and 500 ppm is added to methyl esters to view the effects on performance and emission characteristics. The 1.32% enhancement in brake thermal engine (BTE) was achieved by adding 250 ppm of nanoparticle in biodiesel. Further, 17.5% and 20% reduction in HC and CO was observed with inclusion of 250 ppm of nanoparticle in biodiesel. The 5% increase in NO_X emission and 27% reduction in smoke opacity were observed during the trail. Pandian *et al.* (2017) investigated the consequence of adding titanium oxide nanoparticles in neat biodiesel. Nanoparticles are added at a proportion of 50 and 100 ppm (mass basis) and fuelled in a constant speed diesel engine to evaluate the performance and emission characteristics. Brake specific fuel consumption (BSFC) was reduced by 1.8% by adding nanoparticles to the biodiesel. Further, 3.1% of smoke emission was reduced by incorporating nanoparticles into the biodiesel. Addition of aluminum oxide nanoparticles has significant improvement in heat release rate and brake thermal efficiency with a marginal increase in NO_X emissions. Anbarasu and Karthikeyan (2016) performed an experimental study on biodiesel and diesel with the addition of cerium oxide nanoparticle in direct injection constant speed compression ignition engine. Cerium oxide (CeO_2) nanoparticle at 100 ppm and 200 ppm is added to methyl esters to view the effects on performance and emission characteristics. The 2.1% enhancement in BTE was achieved by adding 200 ppm of cerium nanoparticle in biodiesel. Further, 6.8% and 11.9% reduction in HC and CO was observed with inclusion of 200 ppm of cerium nanoparticle in biodiesel. The 3.8% increase in NO_X emission and 4.8% reduction in smoke opacity were observed during the trail.

Many works have accomplished in a reasonable reduction in NO_x emission by introducing the exhaust gas recirculation (EGR). EGR is extremely valuable in lowering the oxygen concentration and flame temperature of fuel during combustion thereby lessening the NO_x emissions (Mahalingam *et al.*, 2018; Murugesan *et al.*, 2013; Pandian *et al.*, 2018; Sajeevan and Sajith, 2016). Nevertheless, there exists a gap in the literature on information related to the effect of EGR on engine pattern of a biodiesel-fuelled diesel engine by adding nanoparticle. Hence in the present study, the effect of EGR on emission and performance characteristics of biodiesel doped with 30 ppm, 60 ppm and 90 ppm of nanoparticle under two EGR rates of 10%, and 20% was investigated and compared with neat biodiesel and diesel operation.

MATERIALS AND METHODS

Preparation of Palm Oil Biodiesel

The methanolic solution which comprised of 90% volume of methanol and 10% of sulphuric acid which were mixed at a molar ratio of 16:1 to the palm oil. This sample was then heated (60ºC) at four different time durations (30, 45, 60 and 90 min) by employing a magnetic stirrer with a hot plate. Based on the results, heating for 45 min and under 60ºC were found optimal (Yuvarajan and Ramanan, 2016a, c). The separated biodiesel is washed with warm water at 50°C three to four times and later heated to 110ºC to remove the water. Then, the biodiesel is blended with diesel and designated as B20 (20% biodiesel + 80% diesel) and B100 (100% biodiesel). The CeO_2 nanoparticle additive was added to the B20 blend at 30 ppm, 60 ppm, and 90 ppm and dispersed using an ultrasonicator. Finally, all the above blends were introduced in the diesel for analysis. *Table 1* shows the properties of the modified fuels and diesel.

Experimental Set-up

Research type 4.4 kW immobile engine (speed =1500 rpm; cylinder = 1; compression ratio= 17.5:1) was employed to test the fuels. Various parameters of the engine are listed in *Table 2*. A single rotor eddy current dynamometer having a power, torque and a speed of 800 kW, 10 000 Nm and 11000 rpm respectively was used in the work. The load on the engine was varied by changing the current which induced a magnetic resistance to the motion of the shaft. All these investigations were performed at steady state conditions for results reliability. Prior to testing, the engine was fuelled with diesel for about

TABLE 1. PROPERTIES OF THE MODIFIED FUELS AND DIESEL

	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 in 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 2. SPECIFICATION OF THE ENGINE

Type	Four stroke
Stroke	110 mm
Bore	88 mm
Rated output	4.4 kW
Rated speed	1500 rpm
Compression ratio	16.5
Injection timing	23° bTDC
Loading device	Electric generator

30 min for stabilisation purpose. The experimental work was repeated thrice for maintaining accuracy. Square-root techniques were employed to calculate the uncertainty of measured variables.

RESULTS AND DISCUSSION

The EGR is the effective method commonly used to reduce NO_X emissions for diesel engines fuelled by biodiesel and diesel fuelled engine. Here in the procedure, the portion of exhaust gas containing carbon dioxide (CO_2) is recirculated during combustion to facilitate the enhancement in overall specific heat capacity of the gas mixture thereby reducing the temperature during combustion (Mahalingam *et al.,* 2018). The EGR execution is the simplest and cheapest technique for NO_X reduction in diesel engines. The intake manifold is en-suite with a control valve, which governs the flow rate of gas recirculation. This work employs hot EGR method for reducing the NO_X emissions. EGR flow rate is calculated by measuring the concentration of CO_2 in the exhaust and intake manifold (Mahalingam *et al.*, 2018).

The following equation calculates the EGR rate:

$$EGR(\%) = \frac{\%\text{ of } CO_{2intake}}{\%\text{ of } CO_{2exhaust}} \text{ x } 100$$

In the present investigation, exhaust gas analyser is employed to measure the quantity of CO_2 passing through the exhaust manifold and tailpipe post-combustion. The EGR is varied in the range of 10% and 20% for all modified fuels and results are compared with diesel without EGR.

Characterisation of CeO_2 Nanoparticle

The CeO_2 nanoparticle was synthesised through the Solvothermal method. The size of CeO_2 nanoparticle was found to be 20 nm. *Figure 1* shows the scanning electron microscopy (SEM) and transmission electron microscopy (TEM) image of CeO_2 nanoparticle.

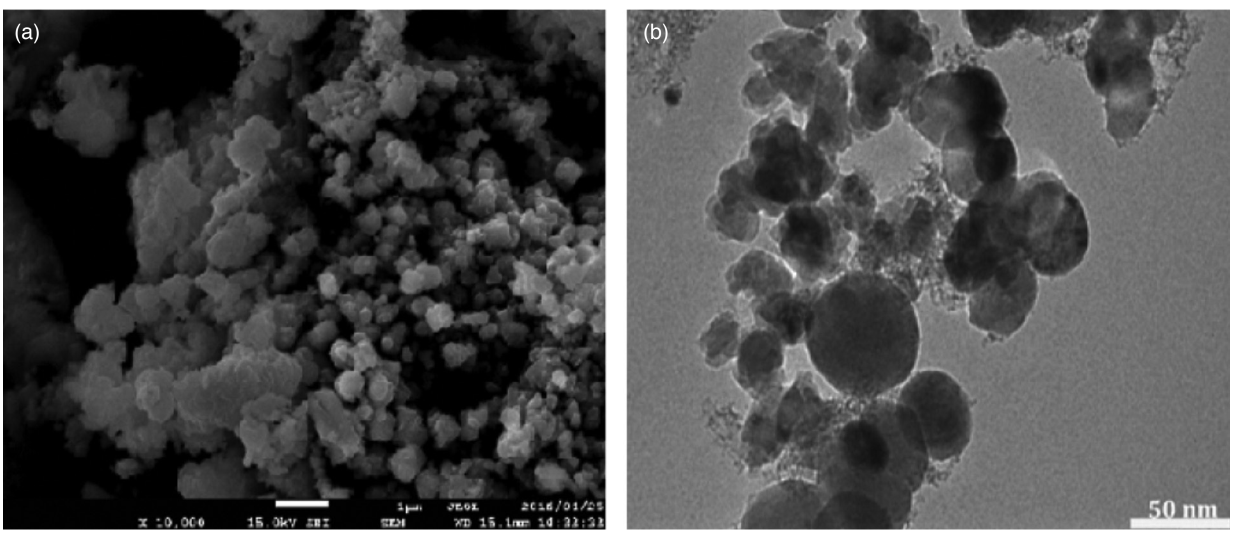

Figure 1. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) image of alumina nanoparticle.

Brake Thermal Efficiency

The deviation of BTE for fuels is shown in *Figure 2*. The BTE from methyl ester and diesel blends is lesser than diesel (Yuvarajan *et al.*, 2016; Venkata Ramanan and Yuvarajan, 2016). Adding 10, 20 and 30 ppm of CeO_2 nanoparticles to BD20 resulted in 0.2%, 0.3% 0.4% increases in BTE, respectively, at all loads when compared to neat BD20. The CeO_2 nanoparticles cause the complete combustion as it acts as the oxygen donor (Pandian *et al.*, 2017; Anbarasu and Karthikeyan, 2015). Comparative fall in BTE was observed for tested fuels at various fractions of EGR (10% and 20% flow rate). Oxygen content in the air reduces with EGR during the combustion and originates poor combustion (Mahalingam *et al.*, 2018; Devarajan *et al.*, 2016; Anbarasu and Karthikeyan, 2016). Lower BTE was observed because of oxygen content and lower combustion temperature of fuels (Devarajan *et al.*, 2017a, c; Mahalingam *et al.*, 2018).

Brake Specific Fuel Consumption

The deviation of BSFC for tested fuels at various conditions is shown in *Figure 3*. BSFC from palm oil methyl ester and diesel blends (BD20) is lesser than diesel (Ramanan and Yuvarajan, 2015b; Devarajan *et al.*, 2017b). Adding 10, 20 and 30 ppm of CeO_2 nanoparticles to BD20 resulted in 0.6%, 0.8% and 1.1% decrease in BSFC, respectively, at all loads when compared to neat BD20. The CeO_2 nanoparticles cause complete combustion as it acts as the oxygen donor (Pandian *et al.*, 2017; Jayaprabakar and Karthikeyan, 2016). The CeO_2 nanoparticles also enhances the heat transfer rate between the fuel and air and exchange the momentum among the fresh charge and burnt products inside the combustion chamber (Devarajan *et al.*, 2017a; Karthikeyan and Jayaprabakar, 2017). The BSFC for tested fuels reduces at various fractions of EGR (10% and 20% flow rate). The oxygen content in the air reduces with

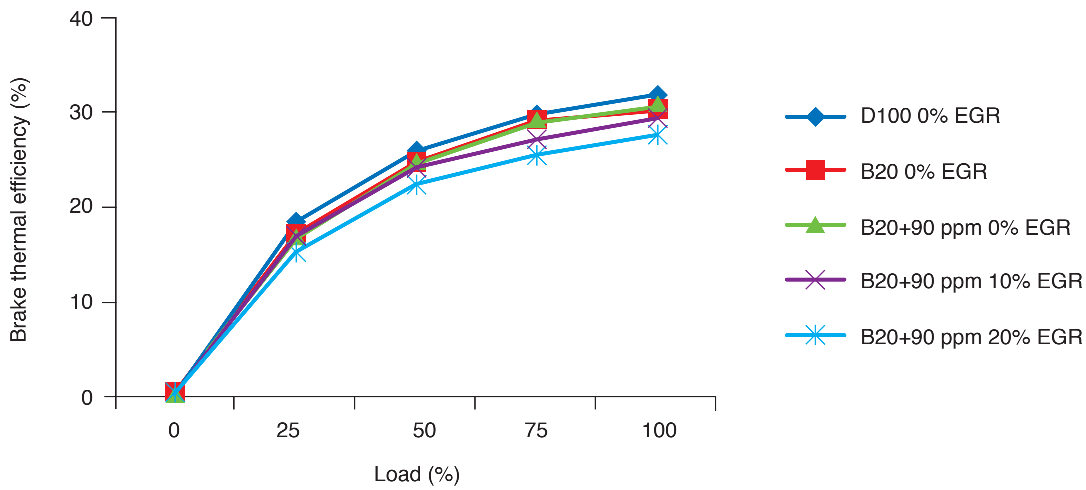

Figure 2. Variation of brake thermal efficiency (BTE) for modified fuels at different exhaust gas recirculation (EGR) rates.

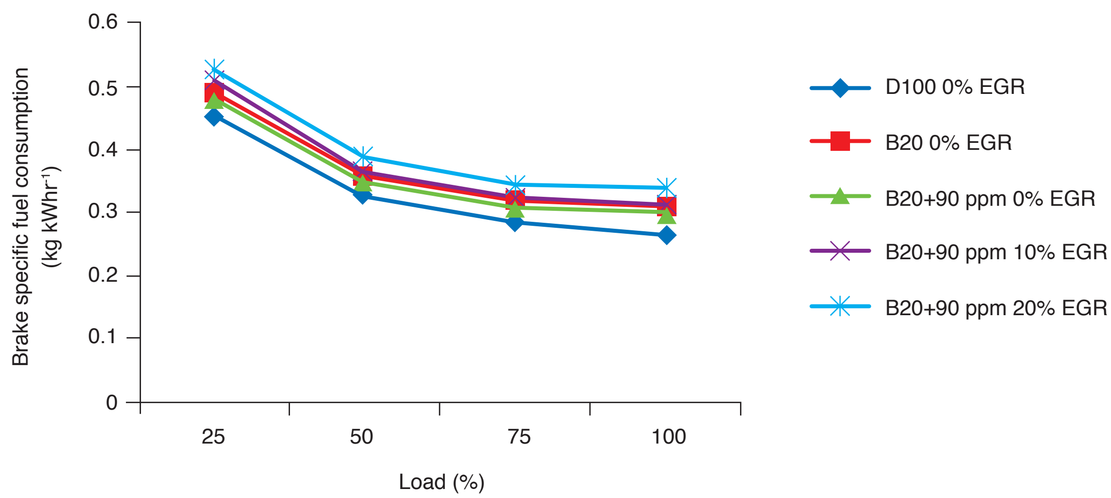

Figure 3. Variation of brake specific fuel consumption (BSFC) for modified fuels at different exhaust gas recirculation (EGR) rates.

EGR during the combustion and giving rise to poor combustion (Mahalingam *et al.*, 2018; Devarajan *et al.*, 2017a). Lower BSFC was observed because of oxygen content and lower combustion temperature of fuels (Yuvarajan *et al.*, 2016; Mahalingam *et al.*, 2018).

Unburned Hydrocarbon Emissions (UBHC)

The deviation of hydrocarbon (HC) for fuels is shown in *Figure 4*. HC emission from palm oil methyl ester and diesel blends is lower than diesel (Devarajan *et al.*, 2017a; Saikrishnan *et al.*, 2017). HC emission reduces with the addition of CeO_2 nanoparticles at various proportions. Adding 10 and 20 and 30 ppm of CeO_2 nanoparticles to BD20 resulted in 2.1%, 2.9% and 3.6% reduction in HC emissions, respectively, at all loads when compared to neat BD20. The CeO_2 nanoparticles increase the combustion efficiency of fuel and promote better combustion and reduce HC emission (Pandian *et al.*, 2017). The reduction in HC emission was observed for tested fuels at various fractions of EGR (10% and 20% flow rate). The oxygen content in the air reduces with EGR during the combustion and originates improved the combustion (Yuvarajan *et al.*, 2017). Lower HC emissions were observed as a result of lower combustion temperature, charge dilution and oxygen content of fuels and improved performance (Mahalingam *et al.*, 2018). Lower O_2 content in EGR forms a rich and heterogeneous air-fuel mixture and engenders low HC Emissions (Mahalingam *et al.*, 2018).

Carbon Monoxide (CO) Emissions

CO is produced due to deficient fuel combustion. The deviation of CO for fuels is shown in *Figure 5*. The CO emission from palm oil methyl ester and diesel blends is lower than diesel (Devarajan *et al.*,

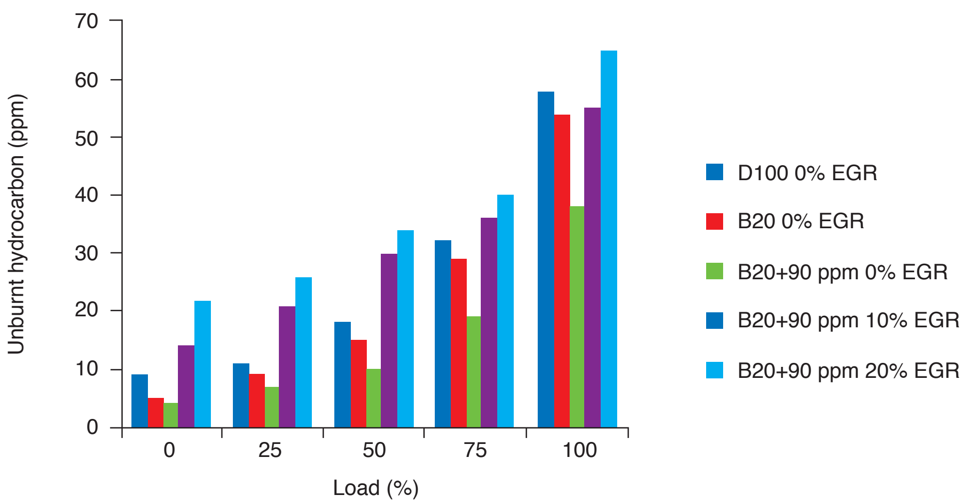

Figure 4. Variation of hydrocarbon (HC) emissions for modified fuels at different exhaust gas recirculation (EGR) rates.

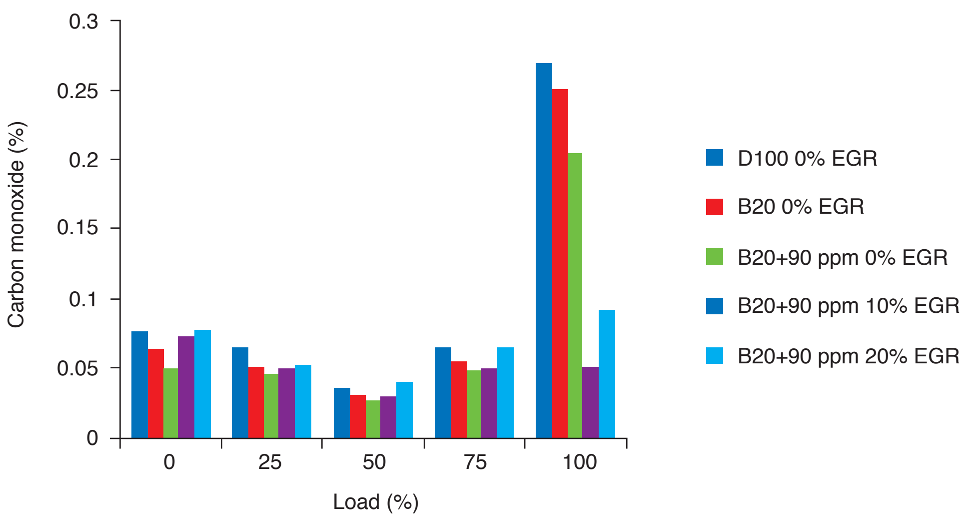

Figure 5. Variation of carbon monoxide (CO) emissions for modified fuels at different exhaust gas recirculation (EGR) rates.

2017a). The CO emission reduces with the addition of CeO_2 nanoparticles at various proportions. Adding 10, 20 and 30 ppm of CeO_2 nanoparticles to BD20 resulted in 3.1%, 3.7% and 4.2% reduction in CO emissions, respectively, at all loads when compared to neat BD20. The CeO_2 nanoparticles increase the combustion efficiency of fuel and promote the combustion and reduce HC emission (Pandian *et al.*, 2017). The reduction in CO emission was observed for tested fuels at various fractions of EGR (10% and 20% flow rate). The oxygen content in the air reduces with EGR during the combustion and gives better combustion (Yuvarajan *et al.*, 2017). Lower CO emissions were observed as a result of charge dilution, lower combustion temperature and oxygen content of fuels and improved performance (Mahalingam *et al.*, 2018). Lower oxygen content in EGR forms a rich and heterogeneous air-fuel mixture and engenders low CO emissions (Mahalingam *et al.*, 2018).

Nitrogen Oxide Emissions

The formation of NO_X emissions during the combustion depends on the availability of residence time and excess oxygen and elevated combustion temperature. The deviation of NO_X for fuels is shown in *Figure 6*. The NO_X emission from palm oil methyl ester and diesel blends is higher than diesel (Devarajan *et al.*, 2017a). The NO_X emission reduces with the addition of CeO_2 nanoparticles at various proportions. Adding 10, 20 and 30 ppm of CeO_2 nanoparticles to BD20 resulted in 3.1%, 3.3% and 3.9% reduction in NO_X emissions, respectively, at all loads when compared to neat BD20. The CeO_2 nanoparticles in biodiesel and diesel mixture lower the cylinder temperature during combustion by making the air-fuel mixture leaner and thus reducing the NO_X emission. Further, CeO_2 nanoparticles increase the combustion efficiency of fuel, promote better combustion, and reduce NO_X emission (Pandian *et al.*, 2018). EGR introduction at various fractions (10% and 20% flow rate) results in significant NO_X emission. Adequate availability of oxygen present in the exhaust gas reduces with EGR during the combustion and gives better combustion (Mahalingam *et al.*, 2018). Lower NO_X emissions were observed as a result of lesser combustion temperature and oxygen content of fuels (Yuvarajan *et al.*, 2017). Shorter availability of oxygen also causes a reduction in NO_X (Mahalingam *et al.*, 2018).

Smoke Emissions

The deviation of smoke emissions for fuels is shown in *Figure 7*. The smoke emission from palm oil methyl ester and diesel blends is lower than diesel (Devarajan *et al.*, 2017a). The smoke emission reduces with the addition of CeO_2 nanoparticles at various proportions. Adding 10, 20 and 30 ppm of CeO_2 nanoparticles to BD20 resulted in 5.1%, 5.9% and 6.4% reduction in NO_X emissions, respectively, at all loads when compared to neat BD20. The oxygen content in CeO_2 nanoparticles gets bonded during the phase of combustion and lowers the formation of soot (Devarajan *et al.*, 2016; 2017a). Further, CeO_2 nanoparticles increase the combustion efficiency of fuel and promote better combustion and reduce NO_X emission (Pandian *et al.*, 2017). The reduction in smoke emission was observed for tested fuels at various fractions of EGR (10% and 20% flow rate). The oxygen content in the air reduces with EGR during the combustion and gives better combustion (Yuvarajan *et al.*, 2017). The higher availability of oxygen also causes a reduction in smoke emissions during EGR mode (Mahalingam *et al.*, 2018).

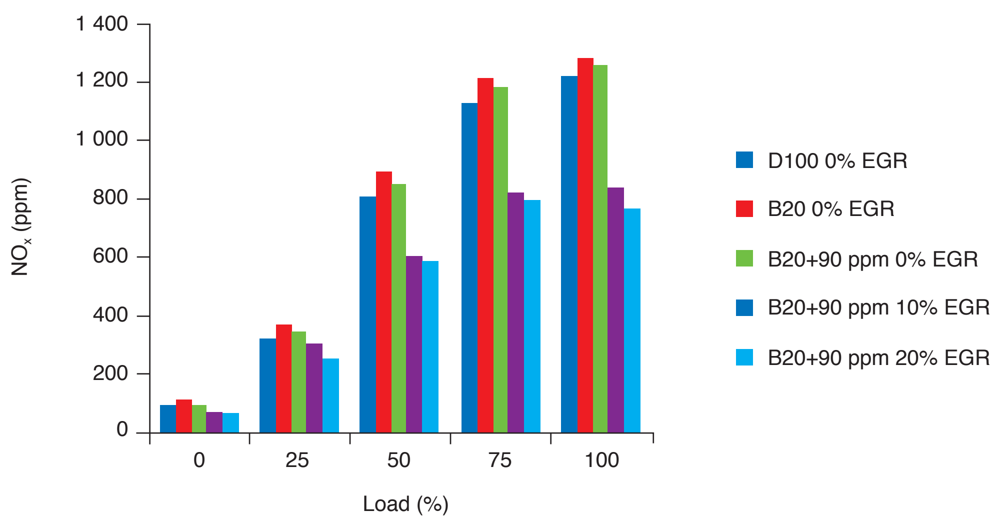

Figure 6. Variation of nitrogen oxide (NO_X) emissions for modified fuels at different exhaust gas recirculation (EGR) rates.

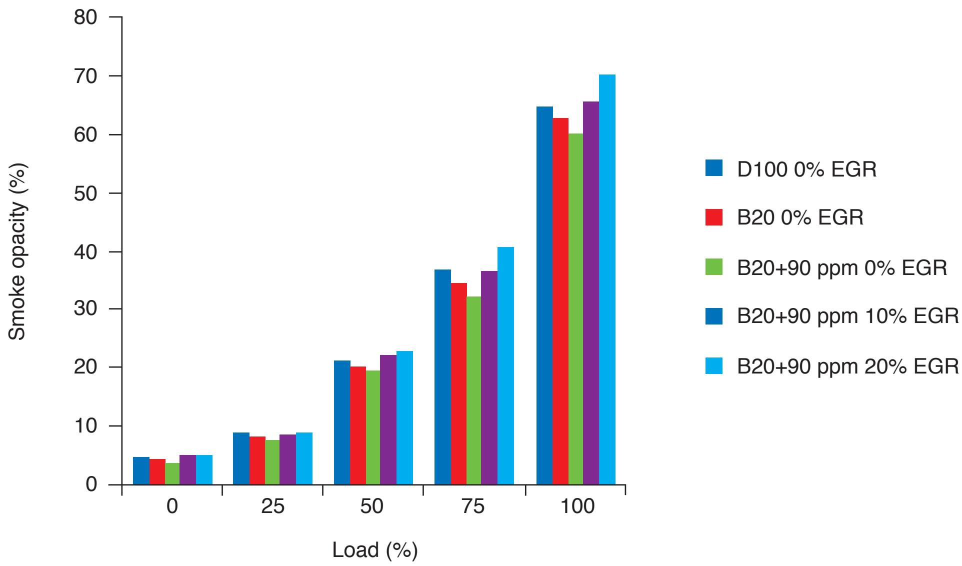

Figure 7. Variation of smoke emissions for modified fuels at different exhaust gas recirculation (EGR) rates.

CONCLUSION

This work examines the effects of CeO_2 nanoparticle on neat palm oil methyl ester and diesel blends on the performance and emissions of the unmodified research engine. Three concentrations of CeO_2 nanoparticles are added at 10 and 20 and 30 ppm to palm oil methyl ester and diesel blends respectively and was used as fuel in the research engine at 0%, 10% and 20% EGR rates. The findings on the engine's emission are as follows:

1. Neat palm oil methyl ester becomes miscible with diesel with no phase separation.
2. Palm oil methyl ester does not require any solvents/surfactants blending with diesel.
3. BTE increased and BSFC reduced with increasing CeO_2 nanoparticles fraction in the palm oil methyl ester and diesel blends. Nevertheless, both the parameters suffered at 10% and 20% EGR rate.
4. CO and HC emissions remained low for neat palm oil methyl ester and diesel blends. A maximum reduction of up to 3.6% and 4.2% of CO and HC emissions were obtained respectively for BD20. Further, these emissions were reduced with the introduction of EGR.
5. NO_X and smoke emissions drop drastically with increasing CeO_2 nanoparticles concentration. A maximum reduction of up to 3.8% and 6.4% of NO_X and smoke emissions were obtained respectively. EGR further reduces the NO_X with a minor increase in other smoke emissions of palm oil methyl ester and diesel blends.

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