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RESEARCH ARTICLE

Performance, Combustion and Emission Characteristics of a D.I. Diesel Engine Fuelled with Nanoparticle Blended Jatropha Biodiesel

Prabu Arockiasamy[1] *, Ramachandran Bhagavathiammal Anand[1]

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Abstract

The effect of nanoparticle as additive in Jatropha biodiesel is experimentally investigated in a single cylinder DI diesel engine with the aim of diluting the level of pollutants in the exhaust and for the improvement of engine performance owing to its potential advantage of high surface area to volume ratio, acting as a catalyst for the better combustion. Alumina and Cerium oxide nanoparticles are blended separately with Jatropha biodiesel at 30 parts per million and the engine performance, combustion and emission characteristics are compared with neat diesel and neat biodiesel as base fuels. For alumina blended test fuel, percentage reduction of NO emission by 9 %, Smoke opacity by 17 %, unburned hydrocarbon by 33 % and carbon monoxide by 20 % are observed along with percentage reduction of NO emission by 7 %, Smoke opacity by 20 %, unburned hydrocarbon by 28 % and carbon monoxide by 20 % for cerium oxide blended test fuel. 5 % improvement in brake thermal efficiency is observed for both the test fuels, due to its high surface area to volume ratio of nanoparticle promoting better combustion by improved atomization, better mixing of air-mixture and rapid evaporation of the fuel.

Keywords

Alumina, cerium oxide, nanoparticle, carbon monoxide, unburned hydrocarbon

[1] Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli-620 015, India

* Corresponding author, e-mail: prabu1603@gmail.com

1 Introduction

There is an increasing demand to find out the biodegradable and environmental friendly fuel to meet the future energy demands. Several legislations were followed for improving the disadvantage of biodiesel fuel such as increased NOx emission and soot particles. To achieve standard emission norms, many studies have been conducted over past few decades. Among them, recent fuel additives namely antioxidants and nanoparticles were preferred for minimizing the NOx emission effectively. Fattah et al., [1] used antioxidants namely monophenolic, 2(3)-tert-Butyl-4-methoxyphenol, 2,6-di-tert-butyl-4-methylphenol, diphenolic, 2-tert-butylbenzene-1,4-diol as additive in calophyllum inophyllum biodiesel blends at 2000 ppm (parts per million) and observed percentage reduction of NOx emission by 3.6 % and improvement in brake specific fuel consumption by 1.5 % along with higher emission of carbon monoxide (CO) and unburned hydrocarbon (HC) in a four cylinder, four stroke, water cooled, indirect injection diesel engine. Varatharajan et al., [2] conducted experimental investigation in computerized four stroke water cooled single cylinder diesel engine by adding antioxidant additives, N,N′-diphenyl-1,4-phenylenediamine and N-phenyl-1,4-phenylenediamine at 1000 and 2000 ppm with soybean biodiesel and observed 14 % increase in CO, 16 % increase in HC emission, 9 % reduction in Nitric oxide (NO) and 0.8 % reduction in brake thermal efficiency (BTE). Similarly, when N, N-diphenyl-1,4-phenylenediamine at 150 ppm was blended with jatropha diesel blends, 16 % reduction in NO was observed with higher emission of HC and CO [3]. From the antioxidant studies, it is observed that antioxidants as additive in fuel was effective for NO reduction, whereas the brake specific consumption, HC and CO emission increases for antioxidant addition. In contrast, when nanoparticles were used as additive in fuel, significant improvement in both performance and emission characteristics were observed.

Sajith et al. [4] experimented with cerium oxide nanoparticle at 20, 40 and 60 ppm addition in jatropha biodiesel and observed significant reduction of NOx by 30 % and HC by 40 % in a four-stroke, single cylinder, water-cooled compression ignition. They observed that the significant reduction of NOx and HC emission were mainly due to the catalytic activity of nanoparticle. Mean while, Selvan et al. [5] added cerium oxide nanoparticle of 25 ppm in diesel-biodiesel-ethanol blends and found improved brake specific fuel consumption with reduction of Unburned HC, CO, NO and Smoke opacity. Basha and Anand [6] blended Carbon Nanotube at 25, 50 and 100 ppm in Jatropha methyl ester emulsion (5% of water and 2% of surfactants (by volume)) and found drastic percentage reduction of NO by 29 % and smoke opacity by 28 % in a single cylinder, four-stroke, direct injection diesel engine. The same team [7] carried out experimental investigation with alumina nanoparticle, blended at 25 and 50 ppm in biodiesel emulsion fuel and observed drastic percentage reduction of NO by 27 %, smoke opacity by 40 % with marginal reduction of HC and CO emission. Tewari et al., [8] conducted experimental investigation in a single cylinder four stroke direct injection diesel engine with CNT blended at 25 and 50 ppm in honge oil methyl ester and determined substantial percentage reduction of NO by 25 %. Bhagwat et al., [9] established 7.6 % improvement in brake thermal efficiency for 50 ppm addition of graphene to Honge Oil Methyl Ester when compared with neat Honge Oil Methyl Ester. From the nanoparticle study, it is observed that in order to improve both the performance and emission characteristics of engine evenly, nanoparticle will be the most promising additive than the antioxidant.

Table 1 Specification of Nanoparticles

Item	Specification	
Manufacturer	M/s. Alfa Aesar, USA	M/s. Sigma Aldrich, USA
Chemical Name	Alumina (Al2O3)	Cerium Oxide (CeO_2)
CAS No	1344-28-1	1306-38-3
Molecular Weight	101.96	172.11
Average particle size diameter	51 nm	32 nm
Specific surface area	32 m^2/g	30 m^2/g
Appearance	White	Yellow

From the above literatures, the experimental results establish that nanoparticle as additive in fuel results in great impact over the performance and emission characteristics of the engine. In this present investigation, the effects of alumina and cerium oxide nanoparticle as additive in jatropha biodiesel on the performance, combustion and emission characteristics of the engine are experimentally determined in a single cylinder four-stroke diesel engine.

2 Materials

Alumina and Cerium oxide nanoparticle are purchased from Alfa Aesar and Sigma Aldrich Company respectively with specification shown in Table 1. The SEM and XRD images of Alumina and Cerium oxide nanoparticle are determined by Scanning Electron Microscope (Model: VEGA3 TESCAN, Czech Republic) and X-ray Diffraction (Model: Rigaku, Ultima IV, Japan) as shown in Fig. 1.

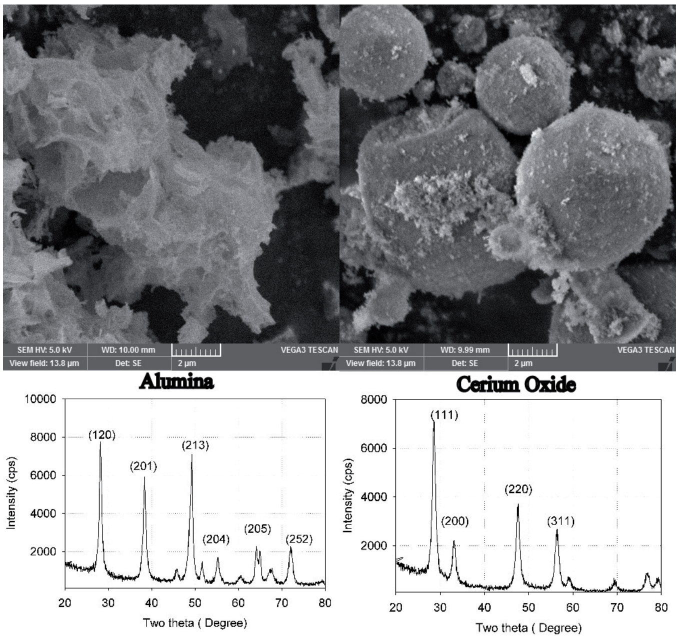

Fig. 1 SEM and XRD images of Alumina and Cerium Oxide nanoparticle

3 Test Fuels

For the preparation of JBD30A test fuel; 30 ppm of alumina nanoparticle is blended with 1 litre of neat biodiesel and for JBD30C test fuel; 30 ppm of cerium oxide nanoparticle is blended with 1 litre of neat biodiesel using ultrasoniactor apparatus set at 50 Hz frequency for 30 minutes and then transferred to fuel tank for the experimental investigation. The properties of test fuels are shown in Table 2. The test fuels are subjected to stability test and found stable for 48 hours without any phase separation as shown in Fig. 2. The engine is started with neat diesel before and after every test fuel, to ensure that previous used test fuel in the fuel injection system is fully consumed.

4 Engine setup

The schematic layout of engine experimental setup is shown in Fig. 3. The engine runs at a constant speed of 1500 rpm at an injection timing of 26 ° bTDC (before top dead centre), injection pressure of 216 bar and produces rated power of 4.4 kW. The engine is electrically loaded by AC alternator and the engine specifications are shown in Table 3. The performance characteristics (brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC)) and emission characteristics (Exhaust gas temperature (EGT), Nitrogen oxide (NO), Unburned Hydrocarbon (HC), Carbon monoxide (CO) and smoke opacity) of the engine are measured and the results are discussed under brake mean effective pressure (bmep). The combustion characteristics are observed using the signals from the piezoelectric pressure transducer (Make: Kistler, Model no: 6613CQ18, Measuring range: 0-100 bar), which is mounted internally on the cylinder head.

Table 2 Properties of Test Fuels

Properties	Density @ 15 °C (kg/m³)	Kinematic Viscosity @ 40 °C (cSt)	Flash point (°C)	Calorific value (MJ/kg)
Neat Diesel	835	2.20	48	42.3
Neat Biodiesel	873	4.10	85	39.5
JBD30A	875	4.25	78	38.9
JBD30C	876	4.30	76	38.7

Table 3 Specification of diesel engine.

Make	Kirloskar
Type	Single cylinder, four stroke, air cooled, direct injection compression ignition engine
Bore x Stroke	87.5 x 110 mm
Compression ratio	17.5:1
Swept volume	661 cm^3
Combustion chamber	Open hemispherical
Spray hole diameter	0.25mm
Cone angle	110°
Rated output	4.4 kW at 1500 rpm
Injection timing	26° btdc

The pressure transducer measures the cylinder internal pressure for fifty consecutive cycles and the mean pressure value is calculated by averaging the collected pressure data with the help of the data-acquisition software. For measuring the combustion parameters with respect to crank angle, a precise marker disk with trigger mark is placed near the flywheel. The combustion characteristics such as cylinder pressure and heat release

Fig. 2 Stability images of Alumina and Cerium Oxide nanoparticle test fuel

rate are measured at rated load of the engine and are discussed against crank angle in the following section. The exhaust gas from the engine such as CO, HC and NO are measured using AVL 444 Digas analyzer and the smoke opacity is measured by using AVL 437 smoke meter. All the tests are carried out for three times under steady state condition and the observed uncertainties for NO, unburned HC, CO, Smoke opacity and BTE are ±1 ppm, ±1 ppm, ±0.01 % Vol, ± 1 % and ± 1.5 % respectively.

5 Results and Discussion

5.1 Brake specific fuel consumption (BSFC) & Brake thermal efficiency (BTE)

The Variations of BTE and BSFC for the test fuels under bmep are shown in Fig. 4 and Fig. 5 respectively. Lower brake thermal efficiency and higher brake specific fuel consumption are observed for neat biodiesel compared to the neat diesel, due to its lower calorific value and higher density nature of biodiesel causing poor atomization of the fuel. The observed values of BTE and BSFC for neat diesel and neat biodiesel are 32.4 % & 0.263 kg/kWh and 28.5 % & 0.318 kg/kWh respectively. However, improvement in BTE and BSFC are observed for JBD30A and JBD30C test fuels as 30.2 % & 0.301 kg/kWh and 30.1 % & 0.303 kg/kWh respectively due to its high surface area to volume ratio of nanoparticle, resulting in fine atomization and rapid evaporation of fuel promoting improved brake thermal efficiency [6].

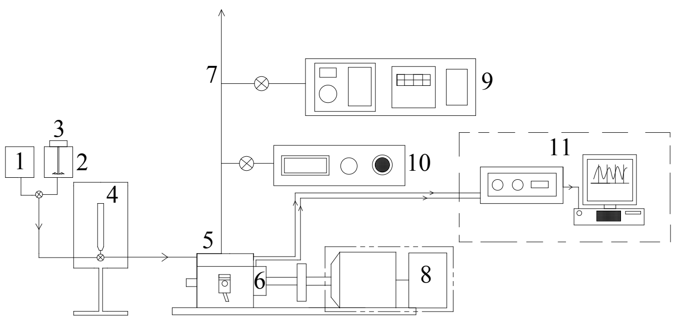

Fig. 3 Schematic layout of engine experimental setup

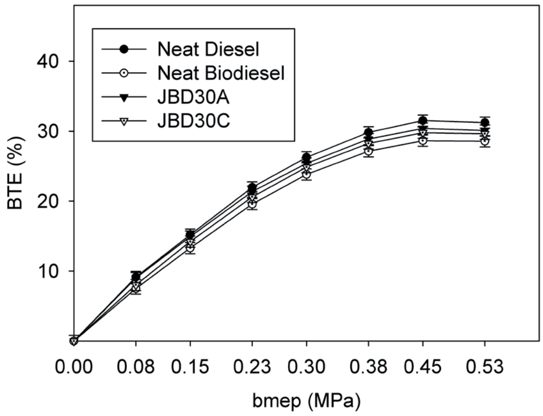

Fig. 4 Variations of BTE with respect to bmep

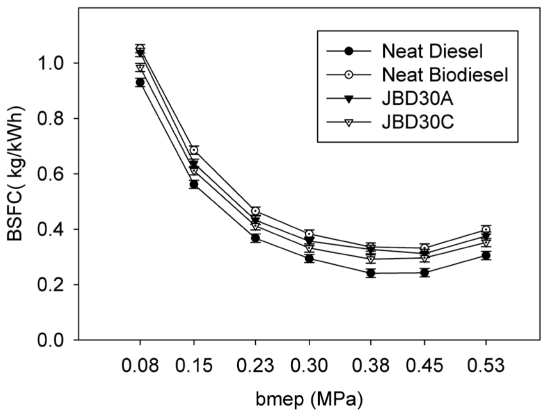

Fig. 5 Variations of BSFC with respect to bmep

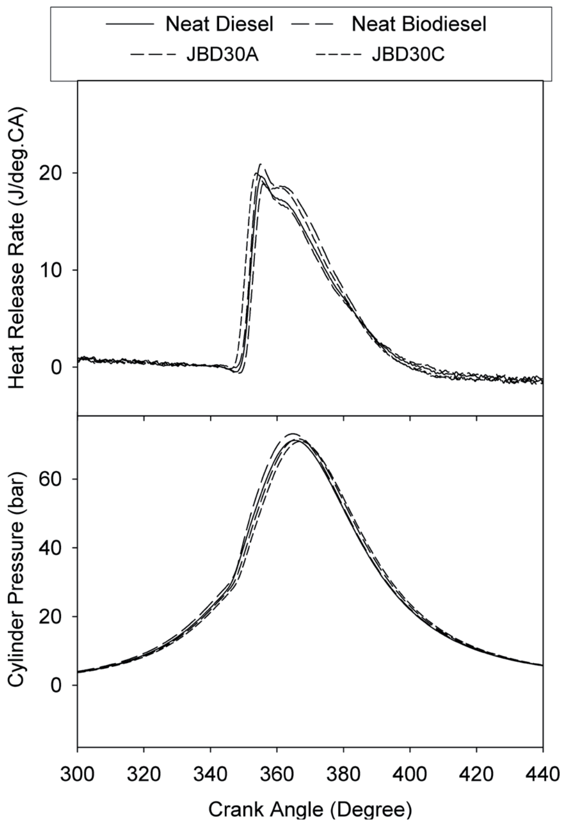

Fig. 6 Variations of Heat release rate and cylinder pressure with respect to crank load at rated load.

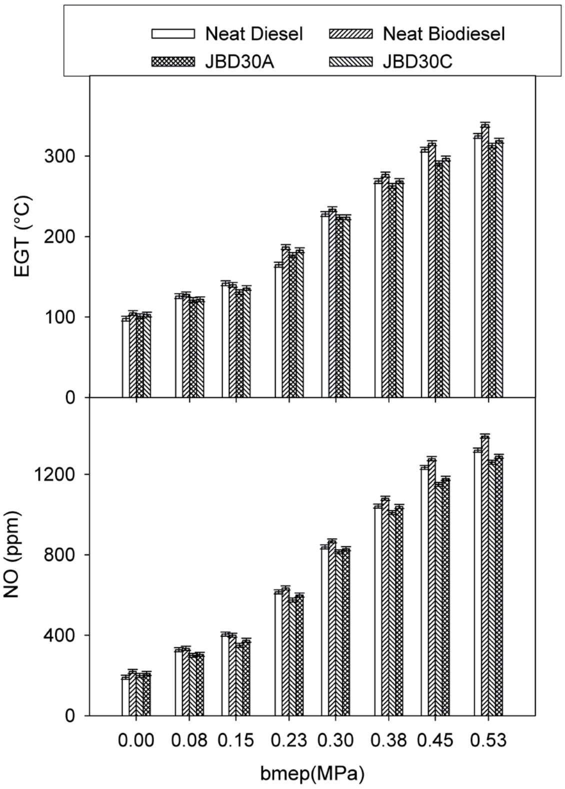

Fig. 7 Variations of NO and EGT with respect to bmep

5.2 Cylinder Pressure and Heat Release Rate

The variation of cylinder pressure and heat release rate with respect to crank angle at rated load is shown in Fig. 6. Higher cylinder pressure and heat release rate are observed for neat biodiesel than neat diesel fuel, due to the rich oxygen content of biodiesel causing sudden burning of fuel during the uncontrolled combustion phase [10]. But for the nano particle blended test fuels JBD30A and JBD30C, lower heat release rate and cylinder pressure characteristics are observed which is due to the advancement of combustion phase [11] by improved atomization and rapid evaporation of fuel [7].

5.3 NO emission & EGT

Figure 7 illustrates the effect of test fuels on NO & EGT under bmep. Biodiesel being an oxygenated fuel ameliorates the rate of oxidation during combustion and results in high local temperatures [12]. At higher temperature, the nitrogen present in air combines with oxygen and forms a series of gas phase reactions resulting in NO emission [13]. The observed NO emission for neat diesel, neat biodiesel, JBD30A and JBD30C are 1320 ppm, 1390 ppm, 1260 ppm and 1290 ppm respectively and the percentage reduction of NO emission for JBD30A and JBD30C are 9 % and 7 % respectively, when compared with neat biodiesel. Reduction in EGT are observed for the test fuels JBD30A and JBD30C as 313 °C and 319 °C respectively, when compared with EGT of neat diesel and neat biodiesel by 325 °C and 339 °C respectively. Significant reduction in both NO and EGT are observed for the test fuels, due to the scavenging of

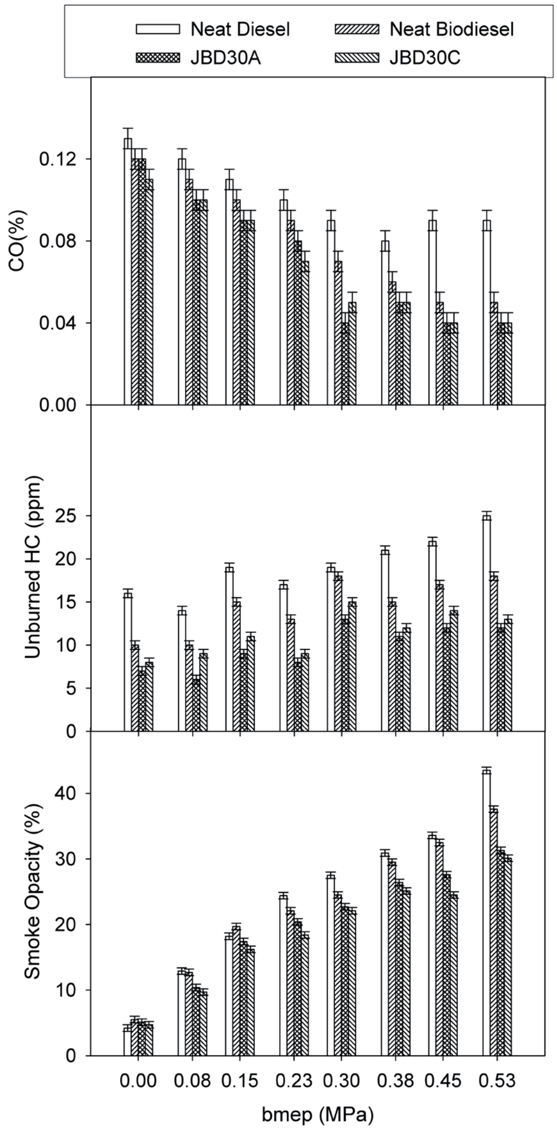

Fig. 8 Variations of CO, Unburned HC and Smoke opacity with respect to bmep

nitric oxide radical by the nanoparticle, that are responsible for the formation of NO [14].

5.4 CO, Unburned HC and Smoke opacity

Figure 8 illustrates the effect of test fuels on CO, Unburned HC and Smoke opacity under bmep. CO emission is formed mainly due to incomplete combustion of fuel [15] and also by insufficient supply of air during combustion [16].

Lower CO is observed for neat biodiesel when compared with neat diesel, due to its rich oxygen content that helps to burn the charge completely. The observed CO emission for neat diesel, neat biodiesel, JBD30A, and JBD30C are 0.09 % Vol, 0.05 % Vol, 0.04 % Vol and 0.04 % Vol respectively and the percentage reduction of CO emission for JBD30A and JBD30C are 20 % and 20 % respectively, when compared with neat biodiesel. Unburned HC are formed by incomplete combustion of fuel mainly due to the formation of lean charge during the delay period [17]. The observed values of Unburned HC emission for neat diesel, neat biodiesel, JBD30A, and JBD30C are 25 ppm, 18 ppm, 12 ppm and 13 ppm respectively and the percentage reduction of Unburned HC for JBD30A and JBD30C are 33 % and 28 % respectively compared with neat biodiesel. Addition of nanoparticle to biodiesel acts as an oxidation catalyst and enhances the hydrocarbon oxidation by minimizing unburned HC and CO emission [4]. Lower smoke emissions are the indication of complete combustion of the fuel. The observed smoke opacity values for neat diesel, neat biodiesel, JBD30A, and JBD30C are 43.5 %, 37.6 %, 31.3 % and 30.1 % respectively and the percentage reduction of smoke opacity for JBD30A and JBD30C test fuels are 17 % and 20 % respectively, when compared with neat biodiesel. Significant reduction in smoke opacity is observed for the test fuels due to the fast evaporation rate and improved ignition characteristics of the nanoparticles [18].

6 Conclusions

The following conclusions are drawn from the experimental investigation of nanoparticle as addition in Jatropha biodiesel.

1. For JBD30A test fuel - Percentage reduction of NO by 9 %, Unburned HC by 33 %, CO by 20 % and smoke opacity by 17 % are observed when compared to neat biodiesel.
2. For JBD30C test fuel - Percentage reduction of NO by 7 %, Unburned HC by 28 %, CO by 20 % and smoke opacity by 20 % are observed when compared to neat biodiesel.
3. 5% increase in BTE is observed for both the JBD30A and JBD30C test fuels compared to neat biodiesel, due to its high surface area to volume ratio of nanoparticle promoting better combustion by improved atomization, better mixing of air-mixture and rapid evaporation of the fuel.

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