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Original Article

Investigation of Performance and Emission Characteristics of a Diesel Engine Fuelled with Mangoseed Biodiesel and Graphene Oxide Nanoparticles Operated with Exhaust Gas Recirculation

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Abstract - *Conventional fuels used in IC engines, such as diesel, petrol, etc., are on the verge of extent. Bio-diesel acts as an alternative to conventional fuels as it is renewable, biodegradable, nontoxic, and less polluting. The present study explores the effect of several blends of biodiesel and nanoparticles on engine emission and performance. Experiments were carried out for the nanoparticles Graphene Oxide (GO) concentrations of 20ppm and 40ppm with mangoseeed biodiesel blend of 15% and 30% at different varying engine loads of 25- 100% (with an increment of 25%) operated at 5% and 10% EGR. Ultrasonicator was used for the preparation of biodiesl blends with graphene oxides. Engine performance like bth,bsf, CP, NHRR, the mass of fraction brunt and emission characteristics such as NOx, HC, CO_2, CO and smoke opacity were examined. Sample B15GO40ERG5% shows the best results among all the samples tested. CO, CO2, HC, NOX, smoke were 0.09%, 2.9%, 20 ppm, 171 ppm, 6.5%, bsfc and ηbth were 0.3 kg/KWh and 28.5%.*

Keywords - *Graphene oxide, Biodiesel blends, Emission, Engine performance.*

1. Introduction

Diesel prices are high as there is more demand from sectors like agriculture, power, automobile, etc. [1] The growing need for fuel and petrochemical fuels with toxic gas emissions is pushing scientists to create green fuels, particularly biodiesel [2]. In general, governments are considering substituting new fuels for fossil fuels as a result of declining fossil fuel supplies, increased air pollution, and growing fuel costs. From this perspective, government authorities have deemed biodiesel as one of the suitable fuels [3]. Using alternative fuels derived from biomass in diesel engines without changing the engine has been promoted by concerns about global warming issues caused by the combustion of diesel [4]. Alternate fuels obtained from renewable sources play an important part in achieving sustainability. However, the environmental and meteorological characteristics of countries looking for biological resources accessed via alternative fuels [5]. Vegetable oil is produced by a commonly used trans-esterification process that exhibits similar properties. Hence, the blending of biodiesel in different proportions can be used as a substitute for Diesel, or it can be used in blended mode. Engine performance, combustion and emission characteristics were evaluated by many researchers using biodiesel blend to verify its use as an alternate fuel [6].

From the results, it is observed that there is a 25 % rise in ηbth and a drop in 20% bsfc when operated by dosing of GNPS at 50e75mg /l of jatropha biodiesel (JB20) compared to pure (JB20). Additionally, there was a 6%, 5%, and 5% rise in the maximum HRR, the highest rate of pressure rise, and peak cylinder pressure. Moreover, there was a 60%, 50% and 40% decrease in emissions of CO, UHC and NOx from engines at a 25e50 mg/L dosage of GNP. An overall characteristic of engine performance is enhanced when it is operated with a GNP dose of 50mg/L [7]. Emre Aytav et al. evaluated engine performance byproducts of combustion of engine-consuming waste hazelnut biodiesel in different ration as 0, 15 and 30%. The engine was operated at different loads to record emission and performance characteristics. Additionally it is observed, improved BSFC (8.30 %), also increase in ID (3.58 %), and NO (2.87 %). While the decrease in ITE (7.7%), CO (18.37%), and smoke (26.15 %) compared to WHB0 [8]. Vikas Sharma et al. carried out experimentation on the engine with 5 different fuel blends at several loads at 1500 rpm. Fuel blends, namely pure diesel D100, neat waste cooking oil (W100), blended waste cooking oil (B40), and waste cooking oil, graphene oxide 100 ppm, 20% butanol (B40NCP1) and waste cooking oil, graphene oxide 100 ppm B40C1 were used. Blends of B40C1 and B40NCP1 contributed 8.5–8%↓ BSFC compared to W100 due to higher calorific values [9]. To increase the thermo-physical characteristics of COME biodiesel, graphite and reduced GO Nanoparticles (NPs) were used as fuel additives at 50 and 75 parts per million (ppm), according to research by Bayindirli et al. The outcomes showed that, when compared to CO fuel at full load, thermal efficiency (η_{bth}) rise in GNPs additive fuels by 69.2% in CGT50, 11.89% in CGT75, 14.35% in CGn50, and 17.97% in CGn75 fuels, respectively. Decrement in BSFC was recorded by 6.92 %, 11.25 %, 13.36 and 16.28%, respectively, for the samples [10]. This study examines the effect of chromium oxide (Cr_2O_3) nanoparticles blended with Mesua ferrea bio-diesel on diesel engines. The lowest emissions like Carbon-monoxide, unburnt HC, NOx, and smoke opacity values were recorded for BD20Cr2O3DSP 80 and BD20Cr2O3CTAB 80 mg/L samples. It was observed that CO was 31.85 %↓,22.22% ↓, UHC was 22.23 %↓,15.56 %↓, NOx was 6.16 %↓,5.11 %↓and smoke opacity was 62.61 %↓, and 45.87 %↓ , respectively, for the blends [11]. When B20 fuel and nanoparticles were used, the emissions were lower than the conventional diesel. Incorporation of nanoparticles in B20 fuel improved performance and combustion characteristics while also lowering pollutants. The diffusion of nanoparticles of BZnFMO in B20 leads to a substantial enhancement in ηbth (BTE), HRR, and CP, and at the same time, there is a reduction in bsfc. Concurrently, there is a reduction in CO, UHC, NOx and smoke opacity [12]. Graphene oxide was dispersed in different amounts inside a Dairy Scum Oil Methyl Ester (DSOME) diesel blend to create a nanofuel blend. Surfactant Sodium Dodecyl Sulphate (SDS) enables the stability of fuel blend by steady dispersion of graphene oxide nanoparticles. Soudagar, M. E. M. et al. Brake thermal efficiency increased by 11.56%, bsfc decreased by 8.34%, the amount of smoke decreased by 24.88%, and CO by 38.66% for the DSOME2040 blend. There is a sizeable enrichment in emission and performance characteristics [13].

The study's objective was to determine how engine performance emission parameters were affected when it is operated with a diesel blended with grapheme oxide and Oenothera lamarckiana bio fuel. Concentrations of 30, 60 and 90 were utilized for each B20 amalgam. Experimented were conducted at variable engine loads, 25, 50, 75 and 100%, at a speed of 2100 rpm. As per the result, it shows that there is a substantial rise in power and Exhaust Gas Temperature (EGT). Moreover, in addition GO nanoparticles, significant falls in CO (5% - 21%) and UHCs (17% - 26%) were recorded. Nevertheless, under the same circumstances, a minor surge in CO_2 (7% - 10%) and NOx (4% - 8.9%) emissions was witnessed. Nano graphene oxide can be a different petroleum additive for oenothera lamarckiana biodiesel combinations [14]. The author conducted experimentation on 3 different biodiesel namely Evening Primrose, Ailanthus altissima and Camelina sativa. Graphene oxide nanoparticles were blended with all 3 biofuels. Camelina sativa biofuel has better physicochemical properties and serves as a better alternative to Diesel. Engine and emission parameters for all three graphene-oxide blended biofuels were compared with diesel. A decrement of unburnt hydrocarbon, CO, and bsfc with a disadvantage of a rise in NOx emissions was recorded with all biofuels blended with GO. [15] Hoseini et al. inspected the effects of GO, CeO_2 and SWCNTs nanoparticles on the engine characteristics like performance combustion and emission of diesel engines under variable load. Reduction in ignition delay by 10.31%, advanced combustion phase by 18.51%, duration of combustion by 14.61%, CO emission by 23.5%, UHC emission by 24.1%, bsfc by 15.2% was achieved when the fuel is blended with SWCNT nanoparticle. [16] Tamarind seed methyl ester was varied with fuel in the intensity of 10, 20 and 30 percent, along with the aluminum oxide and multiwall carbon nanotubes with 30 ppm and 60 ppm doping. It is concluded that 60ppm Al_2O_3 shows higher thermal efficiency by 1.6% in comparison to tamarind seed methyl ester blends. [17] The use of graphene nanoparticles intensifies the fuel's surface area to volume ratio, improving its ability to mix and react chemically during combustion, leading to improved burning and emission features in compression ignition engines. The findings showed that, when compared to B20GrBHA1000, B20GrBHT1000, B20GrTBHQ1000 respectively, there was a minor improvement in bp and thermal efficiency (ηbth) of around 0.29%, 0.58% 0.585%, and 6.22%, 3.31%., 3.11%, [6] When pure moringa oleifera is utilized in engine with split injection, the premixed and diffused HRR phase with decreased peak CP leads to improved combustion characteristics. EGR flow rate of 10 % to 30% with an interval of 5% was introduced. As EGR discharge increases, NOx emission reduces with a rise in bsfc and emission of UHC, CO [18]. Chaitanya et al. used WPO (Waste Plastic Oil) biofuel. It was blended with 1-pentanol in proportions of 10, 20 and 30% using EGR of 10 and 20%. Implementation of EGR diminished NOx emission to 234 ppm however, there is an increase in emission, HC (5.1 ppm) and CO (0.07%) [19]. Jayabal et al. explored the possible use of dimethyl carbonate and n-butanol with sapota methyl ester blends operated at variable EGR of 5-15% and diesel injection timing 21^0, 23^0 and 25^0 Crank angle before TDC. NOx and smoke pollutants reduce drastically for variable EGR discharge. Furthermore, it reduces HRR and ηbth [21]. S. Rami Reddy conducted experiments using 20% mango seed biodiesel along with the variable injection of 19^0 $23^{0,}$ and 25^0 bTDC. The addition of mango seed biodiesel increases ηbth by 4.54%. Emissions like CO and UHC were reduced significantly by 32.345 and 29.26%. However, NOx emission is increased which was controlled using 5% EGR and advancing injection by 25^0 [37]. Khurshid Ahmad et al. investigated the performance of the engine by using different blends of diesel + butanol (0 – 15%)+mangoseed (20%). Optimum results were obtained for MSB20B5 [38]. B. Prashant et al. investigated that 20% mango seed biodiesel results in enhancement of ηbth by 33.9% [39]. Roh et al. investigated that combustion cylinder pressure decreases marginally with the increasing egr release rate for the dimethyl ether biodiesel blends [20]. The introduction of pilot fueling and EGR exhibits a remarkable decline in Nox. However, there is a rise in CO and UHC emissions. [22, 23] K Vijayaraj et al. studied the effect of mango seed oil on the emission of engines by varying its percentage in an interval of 25% ranging from 0 to 100%. There is a rise in bsfc and NOx at full load. However, he concluded that 25% is the best percentage of blending with diesel for better performance of the engine [24].

Various literature shows that different biodiesel blends can be used to lessen the emissions from engines. The addition of nanoparticles leads to improvement in the burning of fuel which further leads to lessening in CO, UHC and CO_2 emission. However, adding nanoparticles leads to an increase in NOx emission. The introduction of EGR can control increased NOx emissions. The researcher does not explore a combination of mango seed biodiesel, graphene oxide and EGR.

2. Material and Method

This segment deals with the preparation of biodiesel, blending of biodiesel, characterization of nanoparticles, stability of nanoparticle biodiesel blends and experimentation.

2.1. Fuels Used for Experimentation

The diesel fuel used for the experimentation was purchased from HP (Hindustan Petroleum Pvt. Ltd.), Nagpur. Biodiesel prepared from mango seed was purchased from Apex Innovation Lab, Sangali, India. A conventional trans-esterification process is done on extracted fresh oil to transform it into biodiesel, and derivatives such as glycerin are obtained. Graphene oxide was purchased from Tokyo Chemical Industry (India) Pvt. Ltd.

2.2. Preparation of Bio Diesel

The kernel was detached from the mango seed shell by a hammer. Feedstock, i.e. seed kernel, was dried in the sun for 1 week to lessen the moisture content. Biodiesel is prepared by means of a trans-esterification process. This procedure includes mixing raw mango seed oil with methanol/ethanol; further mixture is stirred with a magnetic stirrer and heated to 500 to 650C in existence of catalyst NaOH/KOH. By product of the process contains mango seed biodiesel and glycerol. Glycerol is parted using a separating funnel. To remove the moisture and impurities, biodiesel is washed with distilled water and heated to 900C. Figure 1 shows the trans-esterification process [25].

One step synthesis method of preparation of nanofluid was used as the stability of the nanofluid is superior [26]. The requisite quantity of nanoparticles for every sample was accurately measured by weighing scales measuring 20 ppm and 40 ppm. Diesel and biodiesel were mixed on a volume basis, and nanoparticles were added to the flask for various blends. Ultrasonicator at 20 KHz frequency is inserted in a container for 60 minutes. Intermediate ultra-sonication was preferred so as to avoid overheating of the blended fuels. The configuration of test fuel blends in Table 1.

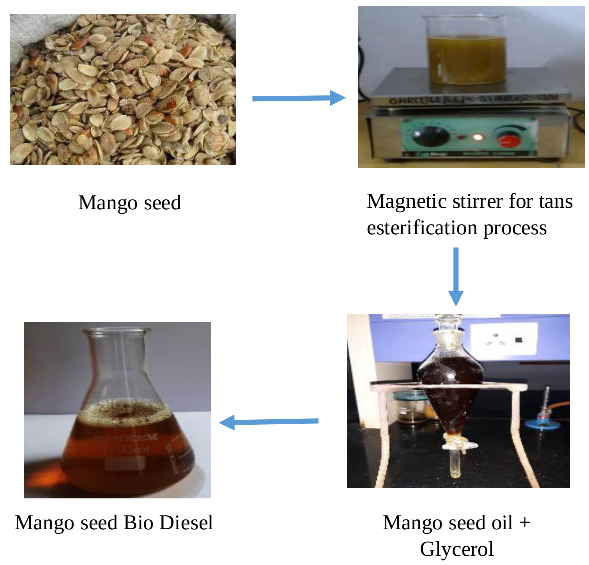

Fig. 1 Transestrification of biodiesel preparation

2.3. Stability of Nanoparticles

Working of turbidity meter on the principle of reflection of light particles present in the sample. It uses an LED light source to measure the level of particles present in the sample. The stability of biodiesel blends was evaluated using a turbidity meter for 5 days.

Nanoparticles were stable for the 3 days; after 3 days, there was a slight variation in their stability. Table **1** shows the turbidity of different samples over some time. Prepared samples were used for testing within 2 days.

Table 1. Turbidity value of different blends of fuel

Sample Name	**Fresh Sample**	**Day 1**	**Day 2**	**Day 3**	**Day 4**
	Turbidity (NTU)				
Pure Diesel	5.4	5.4	5.4	5.4	5.4
B0GO20	13.2	13.2	13.1	12.8	12.7
B0GO40	15.7	15.7	15.6	15.3	14.9
Pure Mango Seed	8.1	8.1	8.1	8.1	8.1
B15GO 20	19.3	19.3	19.1	18.7	18.4
B15GO 40	32	31.9	31.7	31.6	31.4
B30GO 20	22.1	22.1	22.1	20.9	20.6
B30GO40	40	40	39.1	37.8	35.9

2.4. SEM Analysis of Graphene Oxide

The nanoparticles are characterized by an Scanning Electron Microscope (SEM). Figure 2 illustrates the graphene oxide SEM images. As an outcome of the intricate interactions amongst atoms and electrons within the material, the picture depicts the surface morphology of the nanoparticles. The regions of the picture with lesser intensity can be used to infer the crystalline structure of the graphene oxide. The size of the graphene oxide is 14 nm (avg) [27].

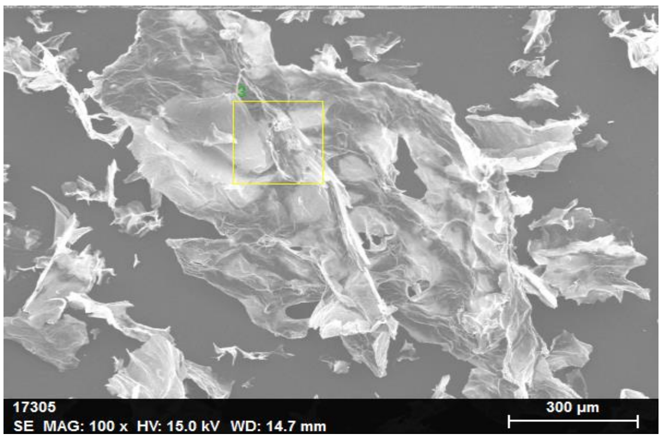

Fig. 2 SEM analysis of GNPs

EDX analysis shows that graphene oxide powder contains 55.98 % C, 40.28% O and 0. 83% S. It contains enough carbon and oxygen atoms, which helps in the enhancement of the combustion process. The presence of carbon and oxygen atoms confirms graphene oxide synthesis.

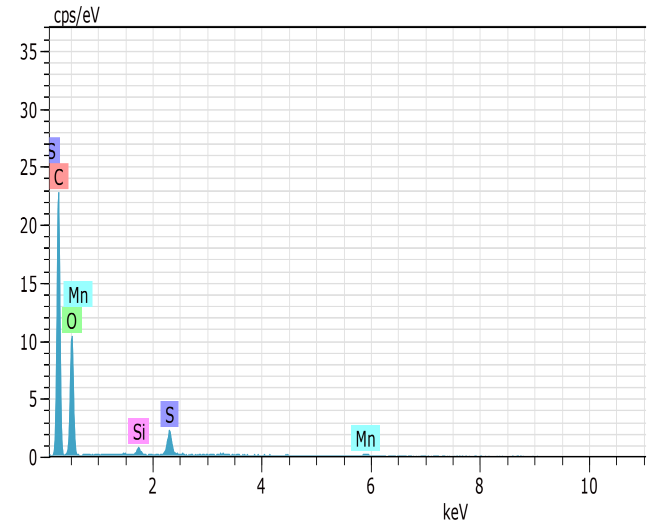

Fig. 3 EDX analysis of graphene oxide

2.5. Fuel Samples Properties

Bio-diesel blended properties are calculated as per the ASTM standards. Amongst the various samples prepared, Mangoseed biodiesel has the lowest calorific value. The addition of graphene oxide enhances the calorific value as well as the cetane number of the samples.

Table 2 shows the various properties of the samples. Minor variations in the properties like kinematic viscosity (µ), dynamic viscosity (ν), flash point, and pour point were observed.

Table 2. Properties of various biodiesel blend

	Sample Properties	Units	Pure Diesel	B15GO 00	B15GO 40	B30GO 00	B30GO 40	Mango Seed
D287	Density @ 25^{0}C	Kg/m^3	821	829	831	836	843	882
D4809	Calorific Value	MJ/kg	42	41.4	42.2	40.56	40.81	40.51
D9358T	Flash Point	ºC	51	56	59	58	60	91
D9358T	Fire Point	ºC	58	65	66	68	65	97
D445	Kinematic Viscosity@40ºC	cSt	2.09	3.07	3.21	3.47	3.56	4.86
D445	Dynamic Viscosity @ 40ºC	cP	1.73	2.54	2.65	2.90	2.99	4.0
D613			50	50.3	50.4	50.6	50.8	52

3. Experimental Setup

The system is comprised of a 4S single-cylinder CRDI VCR engine coupled with an eddy current dynamometer seen in Figure 4. The instruments required for measurements of temperatures, load, air flow rate, fuel flow rate, CA, and combustion pressure are included. A records acquirement system is used to interface these signals with the computer. Details are given in Table 3.

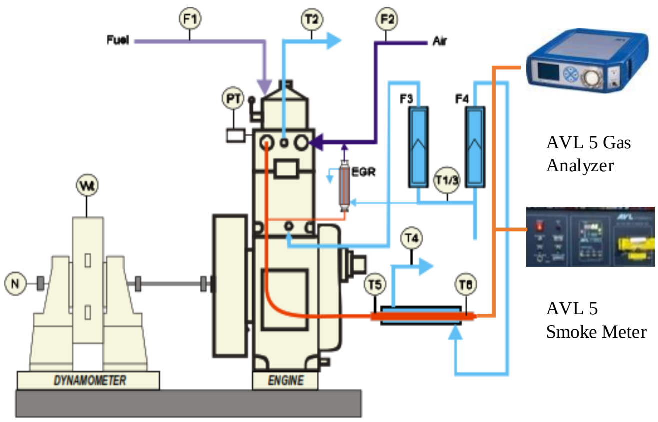

Fig. 4 Schematic view of experimental setup

The common rail direct injection with variable compression ratio engine is equipped with a programmable open electronic control unit for diesel injection, a fuel injector with a crank position sensor, a fuel pump, a pressure regulating valve, and a wire harness. The configuration makes it likely to examine the performance of the engine using a programmable ECU at various CR and EGR settings. Enginesoft software was used to calculate.

Table 3. CRDI engine details

Parameters	Specifications
Power	3.5 Kilowatt
Stroke	110 millimeter
Bore	87.5 millimeter
Capacity	0.661 Liter
Dynamometer	Eddy current
Compression Ratio	18
Injection Timing	23^{o} BTDC

Engine emissions were measured using AVL 5 gas analyzer and AVL smoke meter. Engine combustion parameters like MFB, HRR and cylinder were measured using pressure temperature sensors. Airflow, fuel flow sensors and load cells are used to measure engine performance. All the instruments are calibrated. The precision of the determining parameter is shown in Table 4.

Table 4. Engine parameter accuracy

Parameter	Accuracy (±)
CO	±0.01%
CO2	±0.1 % by vol.
NOX	±10 ppm
HC	± 10 ppm
Smoke	± 1 %
Airflow	± 0.5 %
Fuel Flow	± 1 %
Load	± 0.25 % of F.S.
Speed	± 0.25 %

The engine was initially operated at 1500 rpm and 23o BTDC injection timing with pure diesel to obtain the baseline data. Later on, it operated samples to examine the engine characteristics, such as its emission and performance. Every sample engine is allowed to run for 10 minutes so that sample fuel in the pipeline is consumed completely in order to avoid a mismatch of results. Experimentation is done presence of an expert. The accuracy of measuring instruments is shown in the table.

4. Result and Discussion

The current study investigates the effect of GO nanoparticles, mango seed biodiesel and EGR on different characteristics of running from 25 to 100% engine load with increments of 25%. Tests were conducted for various samples of fuels.

4.1. Fuel Consumption (bsfc) Vs. Engine Load

The volume of diesel spent by the engine to produce 1 unit of braking power is known as brake-specific fuel consumption or BSFC. The deviation in bsfc with varying engine loads with different fuel blends is displayed in Figure 5. For all samples, bsfc generally declines with engine load. The large reactive surface area and strong catalyst activity of the graphene oxide nanoparticle further enhance the micro-explosion occurrences. Improves the combustion efficiency and ensures the nearly complete combustion of fuel, thus lessening the fuel intake. While the addition of EGR deteriorates the combustion and increases the bsfc [28]. The BSFCs observed for the B15G20and B15G40 were found to be 0.32 and 0.31 Kg/KW-hr compared to B15G20EGR5% and B15G40EGR5% as 0.33 and 0.34 Kg/KW-hr at maximum load.

4.2. Brake Thermal Efficiency vs. Engine Load

The efficiency of an engine is the conversion of input thermal energy into useful mechanical power [29]. The addition of graphene oxides ensures the complete combustion of fuel, thus increasing the bsfc. Figure 6 displays the difference of bsfc for all blends tested at different engine loads. The blend of biodiesel and graphene oxides enhances the efficiency. However introduction of exhaust gas leads to a decrease in it. There is a gain of 6.25% in brake thermal efficiency B15GO40 compared to B15GO40EGR10%.

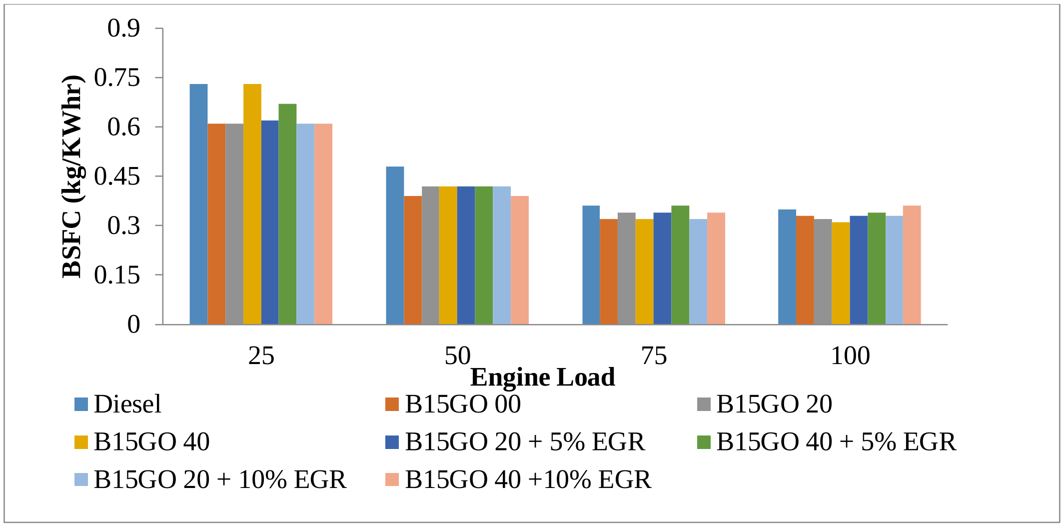

Fig. 5 Variation in BSFC at different load

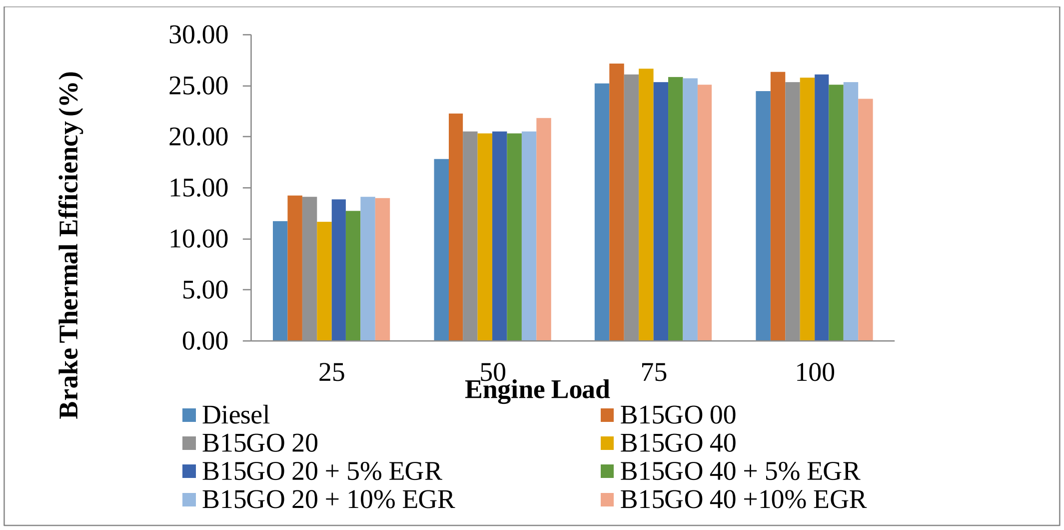

Fig. 6 Variation in brake thermal efficiency at different load

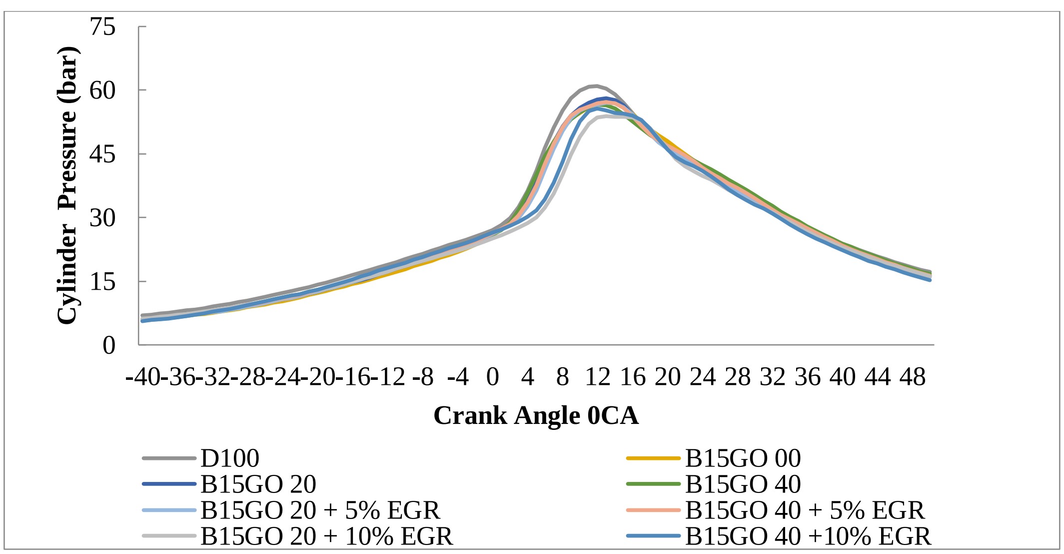

Fig. 7 Variation in CP at different crank angles

4.3. Effect on Cylinder Pressure

The end of the compression stroke and the beginning of the power stroke determine the CP. Cylinder pressure is a function of the quantity of fuel burnt during the uncontrolled combustion process [30]. Higher oxygen and an improved cetane content are produced by adding GO NPs and mango seed biodiesel, and the high volume/surface area raises the cylinder pressure. B15GO20EGR10% shows the lowest CP observed in Figure 7.

4.4. Effect on Fraction of Mass Burnt

Mass fraction burnt is the proportion of diesel used inside a combustion chamber of an engine cylinder at different crank angles. It computes the ID, combustion duration, and rate of mass burn, among other details about the combustion process, using the observed CA and volume [31]. The difference in the amount of fuel burnt with respect to the CA of various biodiesel at EGR is shown in Figure 8. It shows the engine cylinder's fuel combustion rate in relation to the crank angle period. B15GO20EGR5% shows a better rate of mass burnt when compared with B15GO20 when operated at full load.

4.5. Effect on Heat Release Rate

Owing to the loss of heat at the cylinder walls and the consequence of cooling of the fuel vaporization, the negative HRR in the ID period. A decreased ID time and an enhanced cetane number are the reasons for the rise in HRR for all nanofuel combinations, which contribute to higher engine efficiency [32]. Figure 9 displays the deviation of HRR and CA for test samples at full load. Overall, HRR for the al the samples exhibits similar trends with variation in peak. It is highest for 62.5 J/0CA for the sample B15GO40EGR10% compared to B15GO 00 as it has a longer ID and more combustion duration.

4.6. Effect of Blended fuel on Carbon Monoxides

The partial combustion of the diesel results in the production of carbon monoxide. The unviability of oxygen leads to incomplete combustion [33]. Figure 10 shows the CO for different fuel samples at varying engine loads. It is witnessed that the engine operated with B15GO40 at maximum load condition. At lower loads, there is a significant decline in CO emission; however, with growth in engine load, it increases. With the increase in EGR%, it is evident that CO emission increases drastically due to lesser availability of oxygen content.

4.7. Effect of Blended Fuel Additives on Nitrogen Oxides

One of the noticeable emissions from the engine is NOX. NOx formation is due to the combustion of diesel at greater temperatures. NOx emission rises as the load on the engine rises since it operates at a higher air-fuel ratio [34]. The figure shows the variation in NOx emission operated at different loading conditions. The addition of graphene oxide increases the temperature of the engine, which leads to NOx emission. From Figure 11, it is evident that the engine operated with B15GO40EGR5% shows the lowest value of NOx emission at maximum load.

4.8. Effect on Hydrocarbon Emission

In diesel engines, partial combustion of fuel leads to the development of HC emissions [35]. From Figure 12, it is evident that initially, the HC emission is less, but it goes on increasing when operated higher engine load. The addition of graphene oxide with lower concentration initially decreases the HC emission at full load conditions; higher concentration results in a rise in emission. Amongst the different samples, B15GO40EG10% exhibits a maximum of 57 ppm and a minimum of 10 ppm for the B15GO00.

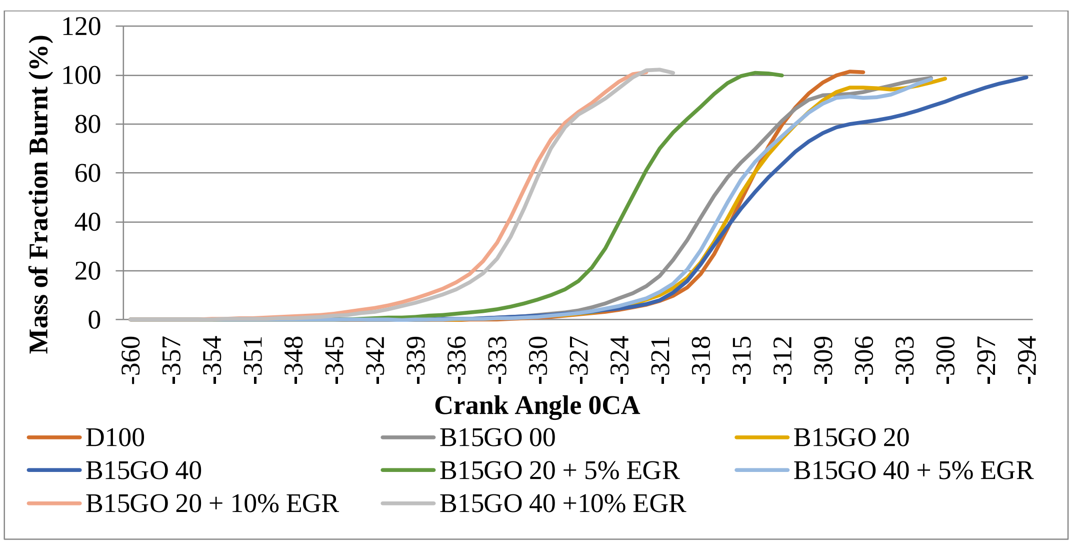

Fig. 8 Variation in mass of fraction burnt with CA

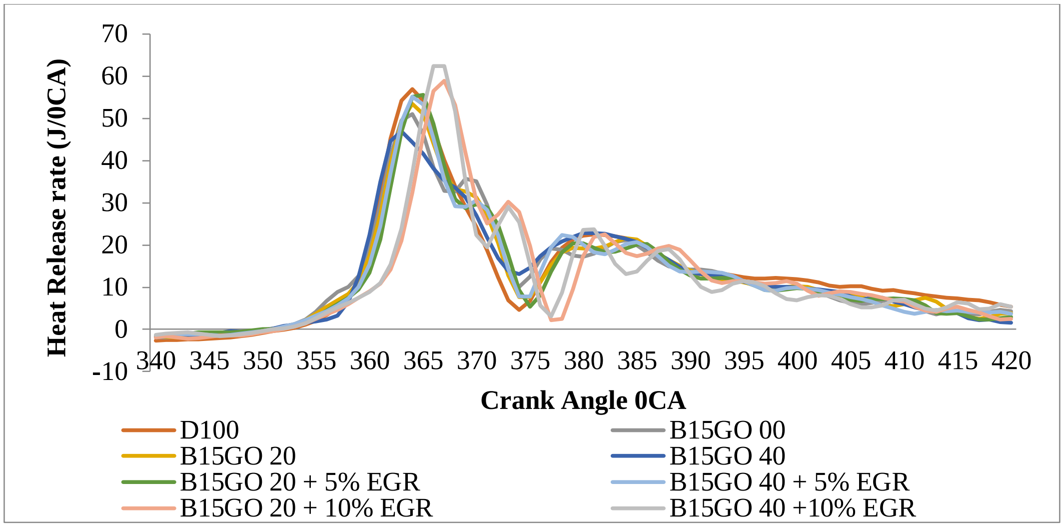

Fig. 9 Variation in HRR with CA

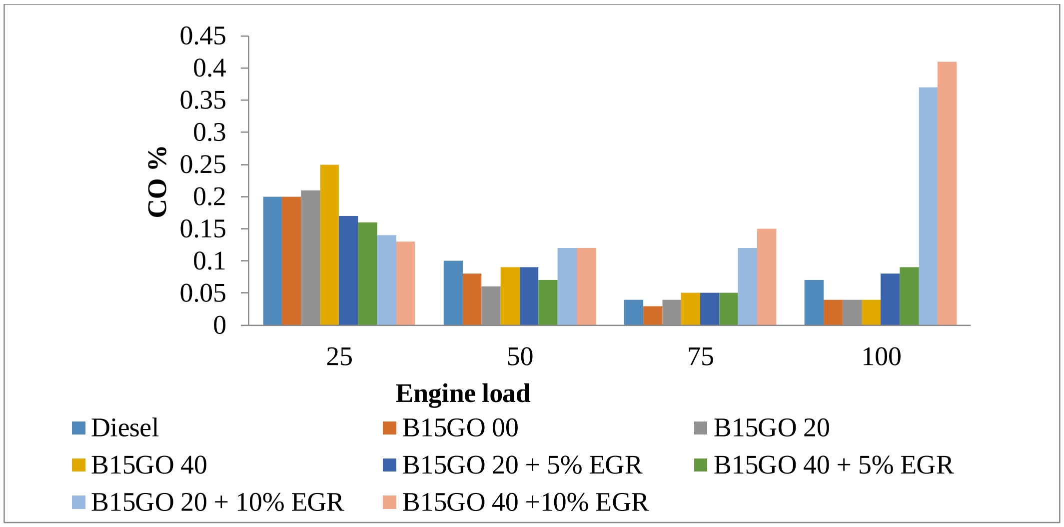

Fig. 10 Deviation in CO at different engine load

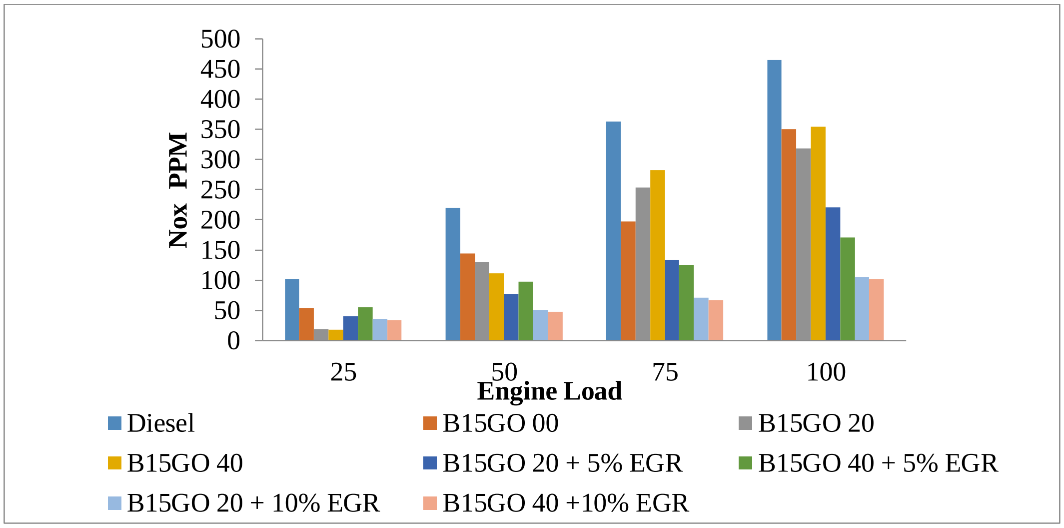

Fig. 11 Variation in NOx emission with different engine load

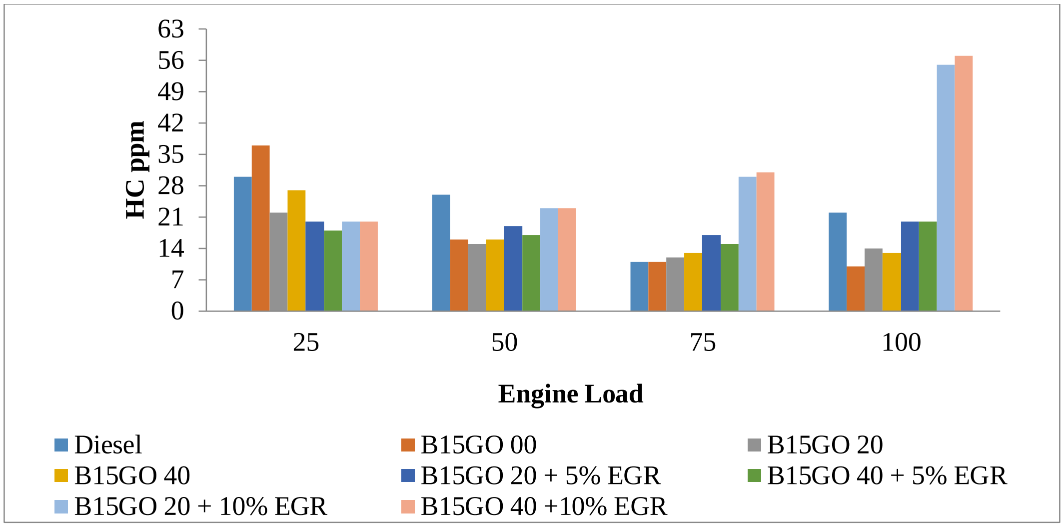

Fig. 12 HC emission at different engine load

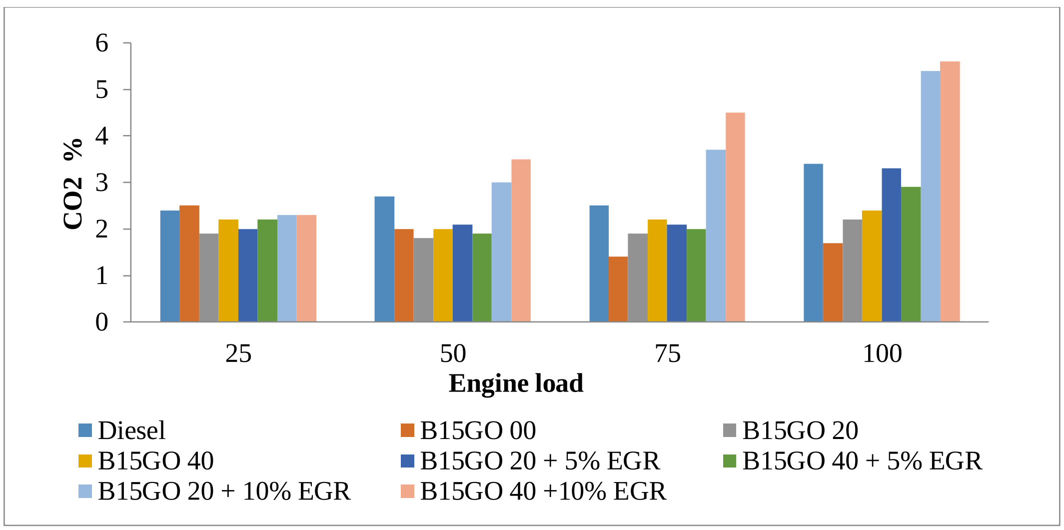

Fig. 13 Variation in CO_2 emission with different engine load

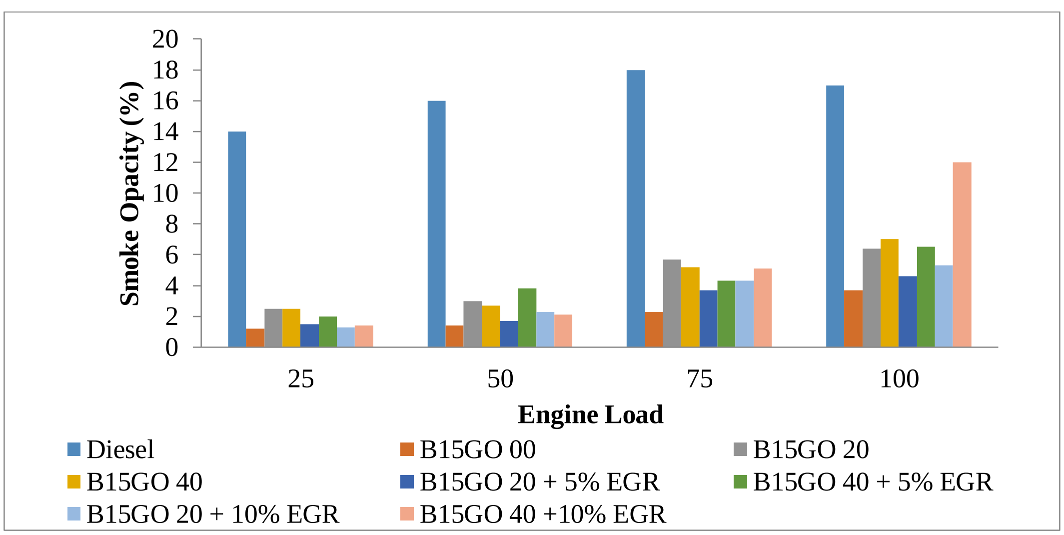

Fig. 14 Variation in smoke emission with different engine load

4.9. Effect of Blended Fuel Additives on Carbon Dioxides

Figure 13 demonstrates a correlation between improvements in fuel oxidation and a rise in carbon dioxide emissions from nano-biofuels. This is because nanoparticles function as catalytic agents for combustion, lowering the amounts of CO and UHCs. Carbon dioxide and other combustion byproducts are used in place of fresh air in the EGR's operation [36]. CO2 emissions are maximum for B15GoO40EGR10% when it is operated at full load condition.

4.10. Effect of Blended Fuel Additives on Smoke

The oxidation of carbon particles is enhanced by the better thermal conductivity of graphene oxide, which enables the nanoparticles to transmit enough heat to different combustion product molecules put on the additive surface [36]. Figure 14 displays the opacity of smoke with respect to different loads. The smoke emission is reduced with the addition of graphene oxide nanoparticles as it enhances the ignition characteristics and reduces the ignition delay. The addition of biodiesel decreases the smoke emission compared to pure diesel. The smoke emission for B15GO20EGR10% is increased by 13.2 % compared to B15GO20EGR5% at full load due to incomplete combustion and soot formation.

5. Conclusion

The present investigation deals with the impact of graphene oxide concentration, mango seed biodiesel and EGR on engine performance, emission and combustion of the engine. The findings of the study can be summarized as:

- Mangoseed biodiesel can be an alternative to diesel fuel when the cost of production of it less.
- The introduction of EGR decreased NOx emission substaintialy at the time with an increase in its percentage. Other emissions like CO, CO2, and HC increase. So, there should be a limit to the EGR percentage.
- The addition of graphene oxides in various fuel samples leads to a decrease in CO, HC and smoke emissions.
- BSCF values for all nanofuel decrease due to complete combustion of fuel as it contains excess oxygen atoms and higher cylinder temperature.
- The rise in ηbth is due to the rapid burning of fuel and least ID and SOC.
- The maximum load condition shows that the HRR of diesel and B15G40 are almost similar.

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Nomenclature

ASTM	American Society for Testing and Material
η_{bth}/BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
BP	Brake Power
EGR	Exhaust Gas Recirculation
CR	Compression Ratio
CP	Cylinder Pressure
HRR	Heat Release Rate
ID	Ignition Delay
MFB	Mass of Fraction Burnt
CA	Crank Angle in degree
bTDC	Before Top Dead Center
CO	Carbon Monoxide
CO2	Carbon Dioxide
HC	Hydrocarbon
NOx	Nitrogen Oxides
GO	Graphene Oxide
B15GO00	15% Mangoseed
B15GO20	15% Mangoseed + GO 20 ppm
B15GO40	15% Mangoseed +GO 40 ppm
B15GO20EGR5%	15% Mangoseed + GO 20 ppm + EGR 5%
B15GO40EGR5%	15% Mangoseed + GO 40 ppm + EGR 5%
B15GO20EGR10%	15% Mangoseed + GO 20 ppm + EGR 10%
B15GO40EGR10%	15% Mangoseed + Graphene Oxide 40 ppm + EGR 10%