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Performance, combustion and emission characteristics of single cylinder CI engine with WCO biodiesel and nanoparticles

Vighnesha Nayak *, A.V. Karthik, B.K. Sreejith, B.G. Prasad, K. Sudheer Kini

Department of Mechanical Engineeering, Affiliated to Visvesvaraya Technological University, Belagavi A.J. Institute of Engineering and Technology, Mangaluru, Karnataka 575006, India

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A B S T R A C T

In this present research work Waste cooking oil (WCO) is used as biodiesel which is blended with aluminium oxide (Al_2O_3), zinc oxide (ZnO) and Graphene nanoparticles with neat diesel, so as to improve the performance of the engine with the reduction in the emissions of the diesel engine. In the experiment B20 biodiesel is optimised from the previous work carried out and added different nanoparticle to the B20. Results revealed that brake thermal efficiency is increased with savage of fuel for B20 with graphene nanoparticle under all load condition. Results also shows decrease in the HC, CO and NOx emission for B20 biodiesel with all the nanoparticles.

1. Introduction

On earth, we are currently burning more ten billion tons of fossil fuels per year worldwide, supplying some 80% of our energy needs through those methods. The consumption of the fossil fuels is expected to increase in the near future to satisfy the needs of mankind. The issue with usage of fossil fuels is the undesirable emissions. The usage of fossil fuels mainly emits CO_2, which is a primary greenhouse gas. The concentration of CO_2 has increased since industrialization and it is a known fact that CO_2, gas released when fossil fuels are burnt, is one of the primary gas responsible for Global warming.

Rise in temperature of earth has resulted in melting of polar ice caps, flooding of low lying areas and rise in sea levels. Other emissions like sulphur, carbon monoxide and oxides of nitrogen are also a great threat to mankind as the can cause serious health complications such as chronic asthma, low lung functioning, chronic bronchitis and cardiovascular diseases. Many researches have been conducted on alternative fuels due to increase in demand for lower fuel consumption and exhaust emission. And they also focused on increasing the combustion efficiency of the engine by conventional fuels.

Biodiesel is a clean burning alternative fuel produced from domestic, renewable resources. The fuel is a mixture of fatty acid alkyl esters made from vegetable oils, animal fats or recycled greases. Where available, biodiesel can be used in compression-ignition (diesel) engines in its pure form with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulphur and aromatics. It is usually used as a petroleum diesel additive to reduce levels of particulates, carbon monoxide, hydrocarbons and toxics from diesel-powered vehicles.

Recycled waste cooking oil (WCO) is harmful to health, but it is not environment friendly to dispose off used cooking oil. So the best solution is to use it for industrial purposes namely to convert it into biodiesel. To minimize the biofuel cost these days, waste cooking oil is used as feedstock. It also estimated that India can supplement 41.14% of its total diesel fuel consumption, if resources like waste cooking oil (WCO) and other bio wastes were used as raw material for biodiesel production. Biodiesel from WCO can reduce the cost biodiesel production since the feedstock costs constituetes approximately 70–95% of the overall cost of biodiesel production. Trans-esterification process is carried out for the purified WCO by a 2-stage process depending upon the free fatty acid test results. After *trans*-esterification process WCO biodiesel is separated from glycerol and washing and drying process is carried out.

Nanoparticles addition to the liquid will improve the thermal conductivity of the liquid. By increasing the thermal conductivity

* Corresponding author.
E-mail address: nayakviggu@gmail.com (V. Nayak).

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Nomenclature

bTDC	Before Top Dead Center	*CO*	Carbon Monoxide
BTE	Brake thermal efficiency	CO_2	Carbon Dioxide
SFC	Specific Fuel Consumption	NO_X	Oxides of Nitrogen
RPM	Revolution Per Minute	*HC*	Hydro Carbon
CI	Compression Ignition	*Ppm*	Parts Per Million
BP	Brake Power		

of the liquid will improve the combustion of the liquid and thereby increases the combustion efficiency. So addition of nanoparticles will improve the combustion of biodiesel in CI engine and increases the performance of the engine. Also nanoparticles will have higher surface to volume ratio hence better combustion can be achieved in the combustion chamber of engine. Nano additives also improves the ignition temperature, reduce the ignition delay and improve the radiative mass transfer of the biodiesel in the combustion zone. Correspondingly addition of nano-particles will reduces the emission in CI engine because of enhanced combustion. Hence it is clear that nanoparticle addition to the biodiesel will improve the performance and emission characteristics of the engine.

Government of India is stringently regulating the emission from the vehicle by Bharath Stage Emission Standards (BSES) norms. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment & Forests and climate change.

The standards, based on European regulations were first introduced in 2000. Progressively stringent norms have been rolled out since then. All new vehicles manufactured after the implementation of the norms have to be compliant with the regulations. Since October 2010, Bharat Stage (BS) III norms have been enforced across the country. In 13 major cities, Bharat Stage IV emission norms have been in place since April 2010 and it has been enforced for entire country since April 2017. In 2016, the Indian government have skipped the BS-V norms altogether and adopted BS-VI norms in 2020.

1.1. Literature review

Nantha K et al. [1] conducted research on pongamia biodiesel to study its effect on the emission and combustion characteristics of the DI compression ignition engine. In this study, a diesel engine for off-road applications was powered with Pongamia biodiesel mixed with diesel. In line with trends in the literature, the experimental results indicate a significant increase in NOx emissions and a reduction in HC, CO and CO2 emissions.

Vishwajit A bhagwat et al. [2] carried out research work on nanoscale graphene - a blended biodiesel engine. Experimental investigations have been carried out to determine the performance and emissions characteristics of a diesel engine using graphene nanoparticles mixed with biodiesel. The nanoparticles of graphene were mixed with biodiesel in the mass fractions of 25 ppm and 50 ppm with the help of a mechanical mixer and ultrasound. The investigation was carried out using an experimental setup consisting of a single-cylinder diesel engine coupled with a dynamic eddy current meter loading device, and the results revealed a significant improvement in the thermal efficiency of the brakes and a significant reduction in the harmful contaminants of the mixture of nanoscale graphene due to the incorporation of nanoscale graphene gives a greater surface area for the reaction and the presence Higher thermal conductivity.

Nadana V Kumar. et al. [3] explored the research work on addition of Aluminium Oxide (Al_2O_3) nano particles blended with waste cooking oil in the Emission, Performance and Combustion Characteristics on a DI Diesel Engine. The blends of biodiesel and nanoparticles were prepared with the aid of an ultra-sonicator and the nanoparticles used were varied in the mass fraction of 25 ppm, 50 ppm and 75 ppm. Experimental investigations were conducted on a single-cylinder four-stroke diesel engine fueled with biodiesel and nanoparticle blends to determine the performance, combustion and emission characteristics. The thermal efficiency of the brakes has been increased in B20 Al2O3, 75 ppm at all loads compared to pure diesel. Specific fuel consumption is higher for B20 Al2O3, 75 ppm compared to pure diesel at full load compared to the different dosage level of the blends. The CO emission decreases with the addition of B20 Al2O3, 75 ppm. The NOx emission is lower for diesel than with the addition of B20 Al2O3.

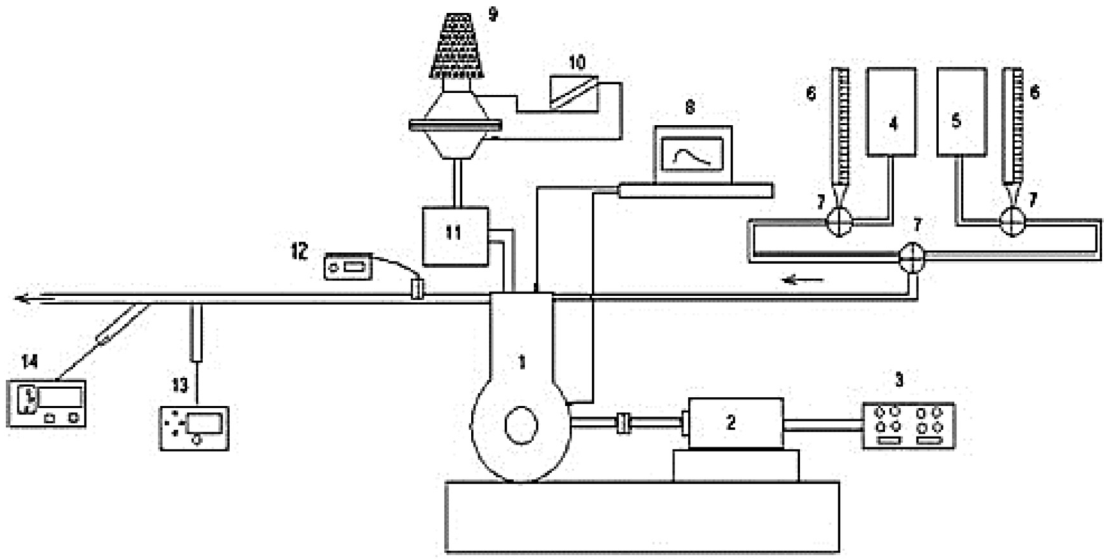
Kumar H et al. [4] carried out the experimental research work Aluminium Oxide as a nanoparticle on performance analysis and emission characteristics of Diesel Engine with diesel and biodiesel as a working fuel. Experimental investigations were carried out to determine the performance of a diesel engine under various load conditions and constant running speed and to compare it with that of pure diesel and with B20. The biodiesel was made from jatropha. The aluminium oxide was mixed with the biodiesel fuel in proportions of 25, 50, 75 and 100 ppm by mass using an ultrasonic vibrator to produce a uniform dispersion. The stability properties of Al2O3 blended biodiesel fuels were then analyzed under static conditions. The study was carried out using an experimental setup consisting of a vertical single cylinder four-stroke diesel engine. All tests were carried out at a constant speed of 1500 rpm. The present study shows that biodiesel blended diesel reduces the thermal efficiency of the brakes and fuel consumption. However, the addition of 45.92 ppm Al2O3 to the biodiesel blended diesel has been recommended to improve the performance of the diesel engine and to reduce the knocking phenomenon caused by the presence of the biodiesel.

Ahmed I. E.L Seesy et al. [6] carried out the research work on Effects of graphene Nano platelet addition to jatropha Biodiesel-Diesel mixture on the performance and emission characteristics of a diesel engine. The addition of 50–75 mg/L GNPs resulted in a shortened ignition delay and accelerated initiation of combustion, which led to a higher gross heat release rate and advancement of the peak gross heat release rate.

The objective of the study reported in this paper is to evaluate performance analysis and emission characteristics of Waste Cooking Oil (WCO) biodiesel in single cylinder CI engine with different Nanoparticles. Variation of performance and emissions of CO, NO_X HC and Smoke with engine load are discussed.

2. Experimental setup and experimental procedure

The experimental investigation was carried out on a single cylinder, four-stroke water cooled, naturally aspirated, direct injection diesel engine. A schematic representation of experimental set up is shown in below Fig. 1. The engine had a compression ratio of 18:1 and was capable of developing 3.5 kW power at a constant speed of 1500 rpm. The injection nozzle has 3 holes of diameter



1. Diesel Engine
2. Alternator
3. Loading Device
4. Biodiesel Tank
5. Diesel Tank
6. Fuel Metering system
7. control valve
8. Data acquisition system
9. Air filter
10. Inclined manometer
11. Surge tank
12. Temperature indicator
13. Five Gas Analyser
14. Smoke meter

Fig. 1. Schematic diagram of the experimental setup.

0.3 mm each with a spray angle of 120°. The injector opening pressure and static injection timing as specified by the engine manufacture were 200 bar and 23° before top dead center. The detailed specifications of the engine are given in Appendix I. A flow meter is a device used to measure the flow rate or quantity of a gas or liquid moving through a pipe. The flow meter is attached to the inlet of the heat exchanger and outlet of the pump. By using this we can control the flow rate of water as per our requirement.

The air flow rate was measured by means of an inclined manometer. A standard burette and a digital stop-watch were employed for the engine fuel flow measurements. K-type (Chromel–Alumel) thermocouples connected to digital indicators measured the exhaust gas temperature. The emissions namely carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), and total hydrocarbon (THC) were measured using an INDUS five gas analyser. CO and CO_2 were determined as percentage volumes whereas THC was measured as n-hexane equivalent in ppm. NO was computed in ppm Smoke was measured in terms of percentage opacity using an AVL 437 smoke meter (standard).

The test fuels used were blended biodiesel and nanoparticles. Initially fuel property tests are conducted for all fuels and values are tabulated in Table 1. The engine performance, emissions and combustion characteristics were recorded at different load ranging from 0% to 100% in increments of 25% along with 10% over load at a constant speed of 1500 rpm. Thus, the effect of Aluminium Oxide, Zinc Oxide and Graphene blended biodiesel on performance, emission and combustion parameters was investigated at an operating condition of 200 and 240 bar injection pressure and 23° before TDC injection timing. The results obtained were compared with that of bio diesel at standard operating condition (220 bar and 23° BTDC). Cooling of the engine was accomplished by circulating water through the jackets of the engine block and the cylinder head. Table 2 indicates the nomenclature of different blends.

The experimental procedure to achieve the objective is divided into three stages. In the first stage, the various physicochemical properties of blended bio diesel were determined and compared with those of the neat diesel which is a base fuel. In the second stage, experiment will be carried out with constant speed of 1500 rpm and varying load 25%, 50%, 75% and 100% of full load for diesel fuel to analyze the performance and emission characteristics of the CI engine. Similarly in the third stage of experiment different biodiesels are used in the same CI engine to analyze the performance and emission characteristics for above said condition. Finally after analysis fuel blend should be optimised on the basis of performance and emission characteristics.

3. Results and discussion

The experimental work were carried out in two stages. In the first stage, the various physicochemical properties of blended bio diesel were determined and compared with those of the neat diesel which is a base fuel. Result obtained is given in above Table 1. During the second stage of the experiment, injection timing, injection opening pressure and compression ratio were kept at 19° BTDC, 200 bar and 17.5 for engine operation. The results obtained is discussed below.

3.1. BP vs load

Fig. 2 shows the variation of Brake Power (BP) with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. Load in percentage is taken along axis and Brake power along Y axis. The Brake power increases linearly with the load because the power is kept constant hence, we

Table 1
Physical properties of fuels.

Sl no	Sample	Constituents	Properties					
			Flash Point (°C)	Fire Point (°C)	Density (g/cm^3)	Viscosity		Calorific Value of the sample (kJ/kg)
						Kinematic (m^2/sec)	Dynamic (Ns/m^2)	
1	B20-(A)	20% WCO + 80% diesel	78	80	0.7935	6.91×10^{-6}	0.5484	55024.83
2	B20-(B)	20% WCO + 80% diesel + 3 g-graphene	100	140	0.8338	4.754×10^{-6}	0.3963	55577.59
3	B20-(C)	20% WCO + 80% diesel + 3 g- Al_2O_3	100	140	0.8335	6.911×10^{-6}	0.5761	52,535
4	B20-(D)	20% WCO + + 80% diesel + 3 g-ZnO	84	88	0.827	6.650×10^{-6}	0.5500	54200.5
5	Diesel		64	80	0.7642	6×10^{-6}	0.4585	42,200

Table 2
Nomenclature of the blends.

FUEL	NOTATION
Diesel	D
80% Diesel + 20% Bio-Diesel	DB
80% Diesel + 20% Bio-Diesel + 3 g- Al_2O_3	DB-A
80% Diesel + 20% Bio-Diesel + 3 g- Graphene	DB-G
80% Diesel + 20% Bio-Diesel + 3 g- ZnO	DB-Z

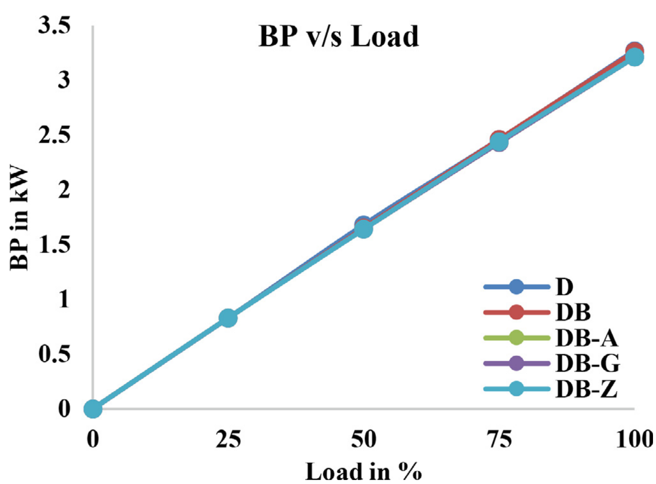


Fig. 2. Variation of BP with load.

get the brake power linearly with the load. The brake power for all types of blend increases as load increases.

3.2. BTE vs load

Fig. 3 shows the variation of Brake Thermal Efficiency (BTE) with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. Because of higher surface volume ratio of nanoparticle will leads to higher engine power which causes the higher heat transfer rate in biodiesel blends. Because of higher heat transfer rate in fuel which enhances the combustion quality and thus higher power output is obtained. The maximum brake thermal efficiency of Diesel, blended biodiesel, Al_2O_3 blended biodiesel, Graphene blended biodiesel and ZnO blended biodiesel is 30.15%, 30.39%, 29.90%, 31.81% and 31.52% respectively for full load conditions.

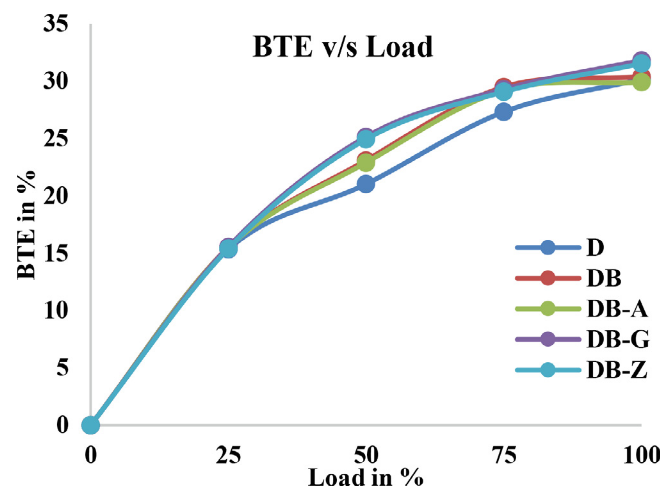


Fig. 3. Variation of BTE with load.

3.3. Specific fuel consumption (SFC) vs load

Fig. 4 shows the variation of Specific Fuel Consumption (SFC) with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. At the low load condition, the specific consumption rate of fuel is high for Diesel and its blends up to quarter load and then decreases. The specific fuel consumption for diesel is slightly more when compared to biodiesel blends this is due to the presence of more oxygen content in biodiesel which increases the combustion properties and nanoparticle presence which will help the fuel to improvise its heat conduction capacity thus increasing the heat release rate and decreasing the specific fuel consumption.

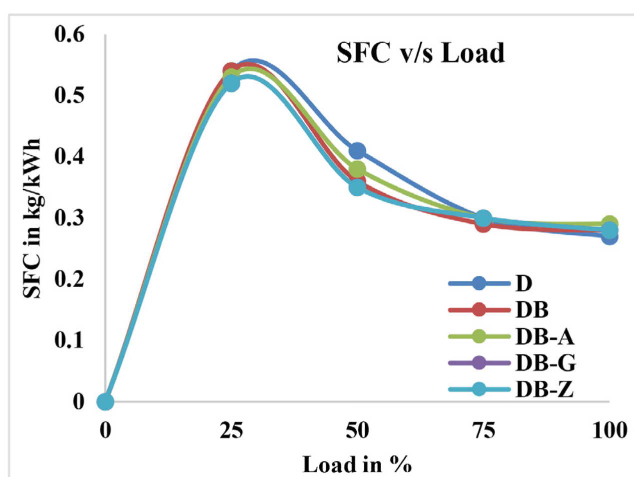


Fig. 4. Variation of SFC with load.

3.4. CO vs load

Fig. 5 shows the variation of Carbon Monoxide (CO) with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. The CO emissions for Diesel were higher. However, CO emissions were marginally lower for the blended biodiesel compared to Diesel, this could be due to the higher catalytic activity and improved combustion characteristics of nanoparticle blended biodiesel with improved combustion that resulted in better performance. The CO emission is reasonably low for biodiesel and its nanoparticle blends when compared to existing neat Diesel.

3.5. HC vs load

Fig. 6 shows the variation of unburned hydrocarbon (HC) emission with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. Due to the presence of more oxygen in biodiesel and its nanoparticle blends there will be improved combustion there by reducing the release of unburnt hydrocarbons when compared to neat diesel.

3.6. NO_X vs load

Fig. 7 shows the variation of Nitrogen Oxide (NO_X) with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. The NO_X emission is also more for the diesel when compared to biodiesel and its blend so the emission characteristics are good for biodiesel when compared to existing neat diesel. As the load increases NO_X emission will increase for all the cases. This is because as load increases, increasing the combustion temperature in combustion chamber causes increase in NO_X emission. NO_X emission slightly decreases with addition of nanoparticle when compare to the diesel fuel alone at higher load. The reduction in the NO_X is might be because of increase in resident time for formation of NO_X emissions.

3.7. Smoke vs load

Fig. 8 shows the variation of Smoke opacity with variation of load for Diesel (D), Biodiesel-Diesel blend (BD) and nanoparticle-biodiesel-diesel blends of Alumina (DB-A), Graphene (DB-G) and Zinc Oxide (DB-Z) nanoparticles. Smoke for B20 and its nanoparticle blend is higher compared to that of diesel. The smoke emission for Graphene is still higher because graphene which is allotropic form of carbon which constitutes smoke. However, Smoke were marginally lower for DB-A and DB-Z, this could be due to higher

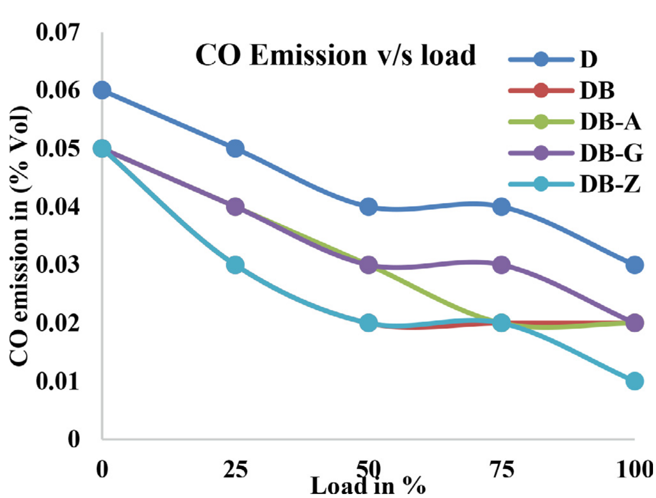


Fig. 5. Variation of CO with load.

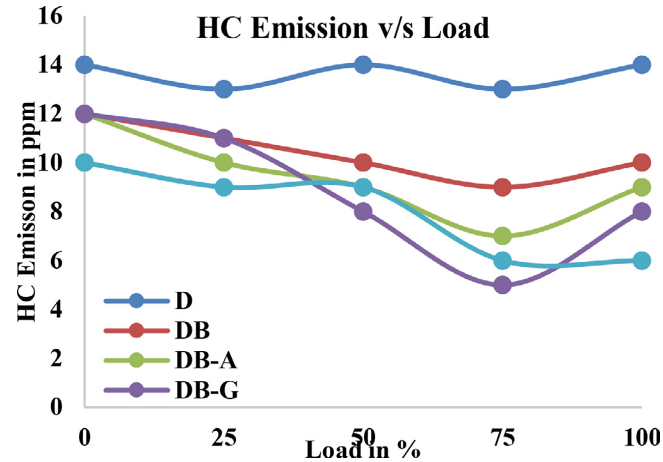


Fig. 6. Variation of HC with load.

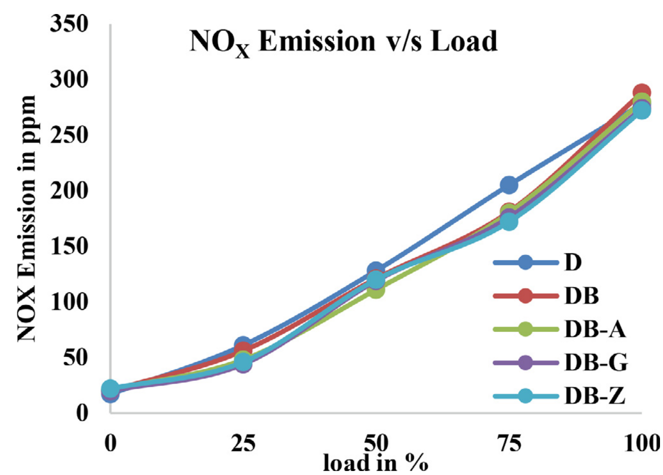


Fig. 7. Variation of NO_X with load.

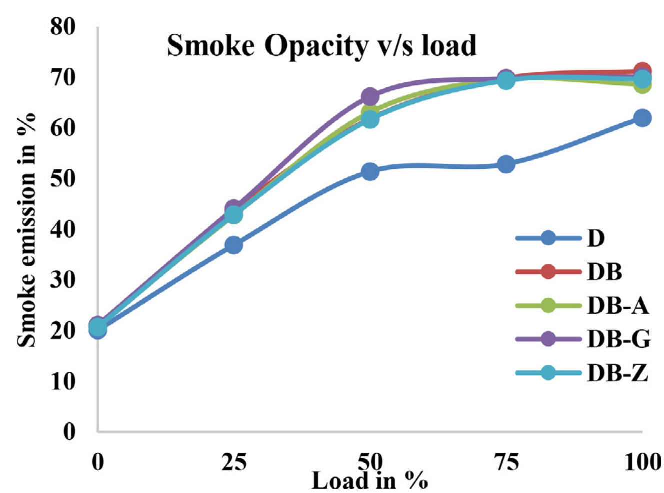


Fig. 8. Variation of Smoke opacity with load.

catalytic activity and improved combustion characteristics. The smoke emission is less for diesel because it contains less oxygen when compared to biodiesel.

4. Conclusions

The extensive study conducted on the single cylinder CI engine with diesel, B20 WCO biodiesel and B20 WCO biodiesel with Al_2O_3, Graphene & ZnO nanoparticle, and draws the following conclusions:

- Brake Thermal Efficiency (BTE) is also high for biodiesel-nanoparticle blends in comparison with existing diesel. Graphene and Zinc Oxide nanoparticles blended biodiesel produces excellent BTE in comparison of other fuels.
- By using nanoparticles in the blend, CO, HC and NOx emissions were decreased when compared with diesel.
- There is increase in smoke emission for all of the nanoparticle blend and also the B20 blend when compared with standard diesel

CRediT authorship contribution statement

Vighnesha Nayak: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision. **A.V. Karthik:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision. **B.K. Sreejith:** Writing – original draft, Writing – review & editing. **B.G. Prasad:** Writing – original draft, Writing – review & editing. **K. Sudheer Kini:** Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table A1
Engine specification.

SL. NO	Parameters	Engine
1	Type of Engine	Kirlosker make Single cylinder four stroke direct injection diesel engine
2	Nozzle opening pressure	200–205 bar
3	Rated power	3.5 kW(4.76HP) @1500RPM
4	Cylinder diameter (Bore)	87.5 mm
5	Stroke length	110 mm
6	Compression ratio	18:1

Appendix A

See Table A1.

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