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ORIGINAL RESEARCH
PAPER



An investigation on the performance and emission studies on diesel engine by addition of nanoparticles and antioxidants as additives in biodiesel blends

Siddavatam Naresh Kumar Reddy*  and Mohmad Marouf Wani

Department of Mechanical Engineering, National Institute of Technology, Srinagar, Jammu and Kashmir, India

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ABSTRACT

The study aims to examine the effects of palm biodiesel blended with additives in the compression ignition (CI) engine. Biodiesel as fuel was limited by challenges such as lower calorific value (CV) and higher viscosity while increasing brake specific fuel consumption (BSFC) and nitrogen oxides (NO_x) emissions. Nanoparticles and antioxidant additives added to biodiesel play an essential role in avoiding the hindrances of biodiesel. The antioxidants combined with biodiesel reduced NO_x emissions by eliminating decomposing peroxides, free radicals, and preventing free radicals' chain reaction. The Significant characteristics of nanoparticles are high CV, high thermal conductivity, and higher surface to volume ratio. These characteristics are used to improve the CI engine's performance and emissions by using nanoparticles blended with biodiesel. Five different test blends of Diesel, B20, B20TO, B20AO, and B20AOTO were prepared. The result showed high brake thermal efficiency (BTHE) and decreased BSFC, exhaust gas temperature (EGT), hydrocarbons (HC), NO_x, and HC emissions by using the B20AOTO fuel blend contrasted with other biodiesel blends.

KEYWORDS

palm biodiesel, titanium oxide, antioxidant NPPD, efficiency, emissions

1. INTRODUCTION

Fossil fuels have a vital role in the evolution of industrial growth, transport sector, agriculture, and many individual needs. The reserves of petroleum fuel decrease every day in the world. Thus, most of the researchers are looking for alternative fuels. Renewable fuels are more attractive to the reserves of fossil fuels. These are facing many challenges, including environmental issues, feedstock, product commercialization, waste glycerol glut problem, and society's acceptance. Biodiesel will be used as a substitute for diesel to face present and future energy demand. Biodiesel is produced from edible and non-edible oils, which are eco-friendly, reliable, non-toxic, and biodegradable. Biodiesel emits low carbon and smoke emissions compared to diesel, which reduces global warming. Biodiesel has a higher density, pour point, viscosity, and molecular weight than diesel. Major biodiesel problems were low fuel atomization, low volatility, injector coking, and piston ring trapping, leading to incomplete combustion due to its viscosity and molecular weight. Biodiesel comprises a long chain of fatty acids containing 10–14 percent oxygen by weight and does not contain sulfur and aromatics. Because of this reason, biodiesel is essential for enhancing complete combustion, decreasing PM, CO, HC, but increasing nitrogen oxide (NO_x) emissions when contrasted with diesel. In comparison, it has a lower calorific value (CV) when contrasted with diesel [1–9].

*Corresponding author.

E-mail: nareshkumar_2017@nitsri.net



According to Mahmud et al. [10], palm oil is a potential biofuel source to be used as a fuel in compression ignition (CI) engine. It is the most efficient oil-bearing crop in efficiency, productivity, availability, and land utilization. It produces a higher yield than all other vegetable oils, so it is available at a competitive price. Because of these parameters, palm biodiesel as fuel has been selected in the current research work. The major biodiesel issues were low heating value, low oxidation stability, high brake specific fuel consumption (BSFC), and high NO_x emissions compared to diesel; to avoid these problems different additives were used. Nano-additives consist of high surface to volume ratio, high calorific value, and high thermal conductivity, So it enhances the performance and emissions of diesel engines. Antioxidant additives in biodiesel effectively reduce the free radicals formation and improve the oxidation stability of the fuel. The TiO_2 nano-additive is eco-friendly, low cost, and non-toxic compared to other nano-additives found in the literature. From the literature review, N-phenyl-1,4-phenylenediamine (NPPD) antioxidant additive appears to effectively reduce the NO_x emissions and enhance the diesel engine's performance compared to other antioxidants.

1.1. Literature review

This section discusses the many works that have reported the effects on a diesel engine operated with using biodiesel, and blended with additives as fuels. Hirkude et al. [11] investigated the influence of waste fried biodiesel in DI CI engine. The results reported that the B50 biodiesel blend has a low CV value, increasing the 6.89% brake BSFC and 6.5% brake thermal efficiency (BTHE) reduced because of the low volatility of biodiesel. The 21–45% of CO, 23–47% of PM, and 50–100% of SO_2 emissions reduced and increased NO_x emissions due to advance injection process and complete combustion of biodiesel. Hasib et al. [12] conducted experiments on the CI engine using mustard biodiesel. The obtained results showed that biodiesel's BSFC increased because of low CV value, and the exhaust gas temperature (EGT) of all blends increased except for B30 blend compared with diesel.

Suleyman et al. [13] studied the effects on CI engine by using canola oil, waste oil, and sefflower oil biodiesels. The results reported CO emissions decreased by 34.28%, hydrocarbons (HC) emissions by 17.49%, and smoke emissions by 50.95%, and NO_x emissions increased by 80.5% and CO_2 emissions by 42.62% with the use of different biodiesels contrasted with diesel. Rahman et al. [14] investigated the effects of CI engine by using palm and jatropha biodiesels. The results showed decreased CO emissions by 23.5–29% and 11.8–17.74%, HC emissions by 34.5–39%, and 31–35% and increased BSFC by 7.1–8.35% and by 8.83–9.29%, NO_x emissions by 22–25% and 17–18%, respectively, for B20 blends of palm and jatropha biodiesel contrasted with diesel. Previous studies reported that biodiesel's significant issues were low heating value, low oxidation stability, high BSFC, and high NO_x emissions compared to diesel; to avoid these problems different additives were used. Some reviewers

reported that biodiesel blended with additives resulted improved performance and reduced emissions on CI engine. Nano-additives consist of high surface to volume ratio, high CV, and high thermal conductivity, So, they enhance the performance and emissions of diesel engines. The antioxidants blended with biodiesel showed a more significant reduction of NO_x emissions by decomposing peroxides, eliminating free radicals, and preventing free radicals' chain reaction.

Basha et al. [15] investigated the diesel engine with constant speed using jatropha biodiesel with aluminum and carbon nanotubes nanoparticles. The results reported that high BTHE by use of JBD25A25CNT blend compared with other blends because these nanoparticles increased the CV of biodiesel blends and lowered ignition delay of combustion. The emission results of the JBD25A25CNT blend showed decreased NO_x and smoke opacity emissions with a high percentage and reduced CO and HC emissions when contrasted with diesel. Pawar et al. [16] investigated the effects of CI engine by blended graphene nanoparticles with HOME. The results reported that high BTHE by use of HOME50GRAPHENE blend compared with other blends because these nanoparticles increased the CV of biodiesel fuel and lowered ignition delay of combustion. The emissions results revealed reduced HC, smoke opacity, NO_x , and CO emissions when using the HOME50GRAPHENE fuel blend instead of other blends.

Praveena et al. [17] examined the effects of performance and emission parameters on CI engine using zinc oxide nanoemulsion with biodiesel. The results reported that the BTHE increased slightly and reduced 10.8% of NO_x , 13% of HC, and 4.6% of CO emissions with GSBD ZnO100 blend as correlated to grapeseed oil methyl ester (GSBD). El-Seesy et al. [18] conducted the effects of CI engine by blended Al_2O_3 nanoparticles with jojoba biodiesel. The obtained biodiesel results with nanoparticle fuel blend showed reduced BSFC by 12%, NO_x by 70%, HC by 60%, smoke opacity by 35%, and CO by 80% as contrasted to biodiesel. Dhana Raju et al. [19] studied the effects of Al_2O_3 nanoparticles blended with tamarind seed methyl ester as fuel on CI engine. The obtained results revealed increased BTHE by 1.6% and reduced CO by 15–51%, HC by 24–68%, and NO_x by 7–9% by using biodiesel with an additive compared to biodiesel.

Musthafa et al. [20] conducted the experiments on CI engine by using DTBP antioxidants with biodiesel. The results reported decreased BSFC by 15%, and increased BTHE by 3.5% by using biodiesel with an additive compared to the B20 fuel blend. NO_x emissions decreased by 13–15% and reduced CO emissions but slightly increased HC emissions resulted by using biodiesel with an additive compared to the B20 fuel blend. Rajendran [21] conducted the effects of CI engine by annona biodiesel blended with phenylenediamine (PPDA) antioxidant additive fuel blend. The results showed that biodiesel with additive decreased up to 25.4% of NO_x emissions contrasted with diesel. Dueso et al. [22] carried out the experiments on CI engine by antioxidant additive from bio-oil blended with sunflower biodiesel. The results



showed that biodiesel with additive reduced smoke opacity and NO_x by 4.4% and 3%, respectively, but it increased HC and CO by 14.3% and 0.7%, respectively, as contrasted with biodiesel. Ashok et al. [23] studied the effects on a diesel engine by antioxidant additives blend with Calophyllum inophyllum biodiesel. The results showed that NO_x emissions reduced by 12.6% for Ethanox blended with biodiesel, and 21% for BHT blended with biodiesel but slightly more emissions of CO, HC, and smoke contrasted with biodiesel.

Velmurugan et al. [24] studied the influence of PHC, DEA, and TBHQ antioxidant additives added to mango seed biodiesel on CI engine. The performance results reported that the same BTHE was obtained with and without antioxidants in biodiesel. The obtained emission results were NO_x emissions reduced by 18.19% by adding additives in the B20 fuel blend, and 7.94% of CO, smoke, and 6.94% of HC emissions increase when correlated with conventional diesel. Kyunghyum [25] studied the impact on oxidation stability and emissions on the CI engine by use of TBHQ, BHT, PrG, a-tocopherol, and BHA antioxidants blended with biodiesel. The results reported that TBHQ antioxidants blended with biodiesel showed better oxidation stability when compared with other blends. There was no difference in NO_x emissions with and without additives added in biodiesel. Kalam et al. [26] carried out CI engine experiments using 4-Nonyl phenoxy acetic acid (NPAA) antioxidant additive blended with palm biodiesel. The obtained results reduced both NO_x and CO emissions when compared with diesel.

2. OBJECTIVE OF CURRENT STUDY

The past studies reported that biodiesel's major problems as fuel on diesel engines were low CV and increased NO_x emissions. Previous literature said that nanoparticles added to biodiesel as fuel on diesel engines would improve engine performance and decrease exhaust emissions expect carbon dioxide. The literature review reported that antioxidants added to biodiesel as fuel on diesel engines would slightly improve performance and reduce NO_x emissions but slightly increase other emissions. The past studies reported some of the disadvantages of biodiesel blended with antioxidants and nanoparticles individually. A few studies discussed the effects of multiple additives blended with biodiesel on a diesel engine. The current investigation compares the impact on a diesel engine using both NPPD antioxidant and TiO₂ nanoparticles blended with Palm biodiesel blends contrasted with diesel.

3. MATERIALS AND METHODS

Palm oil was purchased from Super India Enterprises, Jaipur, India. Diesel fuel was bought from the local city. NPPD antioxidant was obtained from Loba Chemie Pvt. Ltd, Mumbai. Table 1 illustrated the specifications of NPPD antioxidant. From nano research lab the TiO₂ nanoparticles

Table 1. Properties of antioxidant

Antioxidant name	N-phenyl-1,4-phenylenediamine(NPPD)
Molecular weight	184.240
Chemical formula	C ₁₂ H ₁₂ N ₂
Density	Not specified
Melting point	68 °C
Flash point	193 °C

Table 2. Properties of nanoparticles.

Molecular formula	TiO ₂
Appearance	White solid
Density (g/cm ³)	4.23
Molecular weight (g/mol)	79.87
Melting point (K)	2,116
Boiling point (K)	3,245
Solubility in water	insoluble
Ti content (Based on Metal)	99.6%
Chemical composition Titanium	59.33%
Oxygen	40.55%

with an average size of less than 100 nm were purchased. Nanoparticles specifications are showed in Table 2.

3.1. Preparation of fuel blends

Raw palm oil is converted to palm oil methyl ester (POME) using an alkaline transesterification process. Methoxide solution was made by a 1% volume of sodium hydroxide dissolved in 25% volume of methanol with a magnetic stirrer. Raw palm oil was heated up to 65 °C using an ultrasonicator, then methoxide solution was poured into it. The mixture was stirred and maintained for 1 h and then the oil was separated into a separating funnel. After 24 h, oil settled down with two layers due to gravity in separating funnel. The upper part of the separating funnel was crude POME, and the lower part of the separating funnel was glycerol. Now the crude POME was separated with glycerol and later washed with hot distilled water. These crude POME were heated up to 100 °C because it removes the water content of oil, and the oil thus obtained was clean POME. The use of an ultrasonicator prepared different test fuel blends. Table 3 illustrates the different types of fuel

Table 3. Types of blends with composition

Blend Name	Composition
B0	100% Diesel + 0% Biodiesel
B20	80% Diesel + 20% Biodiesel
B20AO	80% Diesel + 20% Biodiesel + 1,500 PPM NPPD antioxidant
B20TO	80% Diesel + 20% Biodiesel + 60 PPM TiO ₂ nanoparticles
B20AOTO	80% Diesel + 20% Biodiesel + 1,500 PPM NPPD antioxidant + 60 PPM TiO ₂ nanoparticles

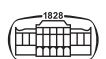


Table 4. Properties of test fuels

Properties	Diesel	Raw palm oil	Palm Oil Methyl Ester				
			B100	B20 Fuel	B20 AO	B20TO	B20 AOTO
Density (kg/m ³)	820	906-911	870	840	839.5	839	832
Viscosity (mm ² /s)	3.40	37.60	4.40	3.50	3.39	3.3	2.75
Flash point (K)	321	496	369	341	344	342	333
Fire point (K)	327	515	399	371	376	374	361
Cetane Number	48	40-44	54.2	52	51.5	51.85	59
Calorific value (MJ/kg)	43.2	36.31	39.8	41.4	41.5	41.9	42.9

blends with composition. ASTM standards were used to find out the properties of the different blends. Table 4 shows the properties of different fuel blends.

3.2. Experimental setup

Figure 1 illustrated the experimental test rig. Single cylinder variable VCR diesel engine with a hydraulic dynamometer was used to perform experiments using different blends. Table 5 shows the specifications of the test rig. DAS consists of the various fuel measurement, digital load sensors, cylinder pressure, crank angle location sensors and airflow rate incorporated with engine setup. Engine Soft software is used to measure the performance parameters of a diesel engine. Multi-gas analyzer was used to measure the exhaust emissions of CO, HC, O₂, CO₂, and NO_x emissions. Table 6 shows the range and resolution of different gasses of the multi-gas analyzer. Table 7 illustrates the percentage of uncertainty and accuracy of the measurements.

4. RESULTS AND DISCUSSION

The current research work illustrates the effects on CI engine by adding NPPD antioxidant and titanium oxide (TiO₂) nanoparticles additives blended with biodiesel. The test were conducted five times in the exhaust gas analyzer to confirm the emission data values.

4.1. Engine performance

BSFC refers to the fuel efficiency of any engine that burns fuel and produces a requirement of power. It is completely dependent on the test fuel blend properties, and the fuel

property of calorific value is majorly affecting the BSFC of the CI engine. BSFC of tested blends varies in load, as illustrated in Fig. 2. BSFC of fuel increase with the increase

Table 5. Specifications of test rig

Parameters	Specifications
Make	TECH-ED
Model	Four stroke single cylinder water cooled VCR diesel engine
Basic engine	Kirloskar
Rated power	up to 4 KW
Bore	80 mm
Stroke	110 mm
Connecting rod length	234 mm
Capacity	552 cc
Compression ratio	12:1 to 20:1
Speed	1,500 rpm
Dynamometer	Hydraulic dynamometer
Piezo electric pressure sensor	0 to 5,000 psi

Table 6. Specifications of range and resolution of the exhaust gas emissions

Measurement	Range	Resolution
NO _x	0-5,000 ppm	1 ppm vol
CO ₂	0-20% vol	0.010% vol
O ₂	0-25% vol	0.10% vol
CO	0-9.99% vol	0.001% vol
Engine RPM	500-6,000 rpm	1 rpm
HC (propane)	0-15,000 ppm	1 ppm
Lambda	0.2000-2.000%	0.0010
Oil Temperature	0-150 °C	1 °C

Table 7. The percentage of uncertainty and accuracy for the measurements

Measurements	Percentage uncertainty	Accuracy
Temperatures	±0.1	±1°C
Engine speed	±0.2	±2 rpm
Hydrocarbon	±0.2	±10 ppm
Carbon monoxide	±0.2	±0.02%
Nitrogen oxides	±0.2	±15 ppm
Crank angle encoder	±0.2	±0.5 CA
Burette fuel measurement	±1.5	±2 CC
Load	±0.2	±1 N



Fig. 1. Experimental test rig

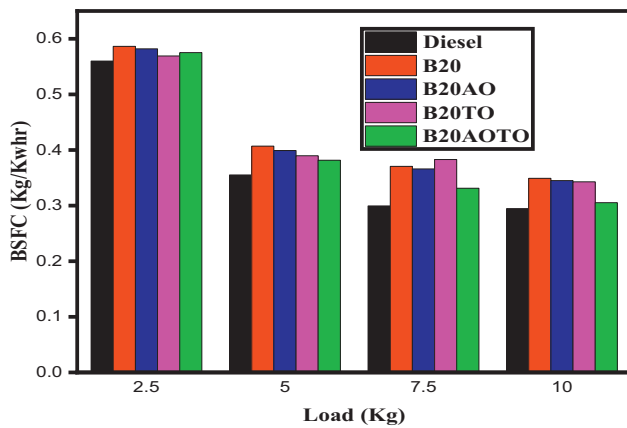


Fig. 2. Brake Specific Fuel Consumption (BSFC) vs. load

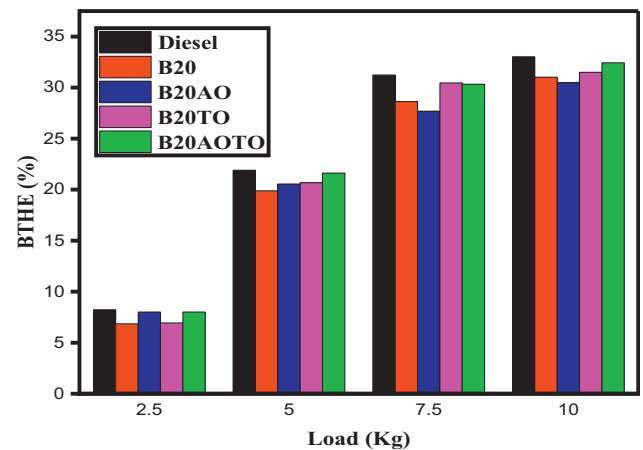


Fig. 3. Brake Thermal Efficiency (BTHE) vs. load

of load on a diesel engine in all cases. It was found that the BSFC of B20 blend was raised when compared with diesel because pure biodiesel produces 5–10% less CV than diesel fuel. Though biodiesel consists of 20% of diesel, it generates 2% of the low CV of diesel. The lower BSFC value was obtained by using the B20AOTO blend as contrasted to B20 blends and farther it showed the same BSFC value at full load compared with diesel. Nanoparticles blended with biodiesel improved rapid evaporation, better air–fuel mixing, high surface-to-volume ratio, high CV, and atomization, resulting in lower BSFC correlated to biodiesel. The friction step down the quality of amine antioxidants is another factor of additives for lower BSFC value.

BTHE shows how efficiently the energy of fuel converted into mechanical work. BTHE appeared as a function of BSFC and it shows the reverse trends according to BSFC trends. BTHE of biodiesel fuel showed less compared to diesel, as shown in Fig. 3. The lower BTHE value was obtained by the use of the B20AOTO blend as contrasted to B20 tested blends and farther it showed the same BTHE value when compared with diesel. BTHE of B20 blends was enhanced somewhat by adding nanoparticles to biodiesel. It is due to the biodiesel blended with nanoparticles, which comprises the high CV and high surface area to volume ratio hence leading to better combustion. Also, the addition of nano additives causes improved thermal stability property, which acts as an oxidation catalyst that leads to enhanced combustion, resulting in higher BTHE. Friction reduction properties of antioxidants cause to increase BTHE of a CI engine at part loads, as shown in Fig. 3. At full load condition, BTHE of a CI engine decreases by antioxidants blended with biodiesel. The reasons for reducing BTHE was ignition delay and heat release rate owing to slightly reducing reaction rate because of the free radicals reduced by antioxidants.

EGT of fuel was influenced by the engine loading and dynamics of the exhaust system. Figure 4 shows that EGT of tested blends varies with load. EGT of tested blends increases by increasing the load on the CI engine. Figure 4 shows the lower EGT of biodiesel as contrasted with diesel. The primary reason for these is the high calorific value of

diesel fuel contributing to higher EGT, which indicates the loss of heat energy through the exhaust. From Fig. 4, EGT of B20 blends with antioxidants decreased and increased by the use of B20 blend with nanoparticles compared with diesel. The blend B20AOTO yielded lower EGT compared to other blends at high load. Nanoparticles blended with biodiesel exhibit higher EGT compared to different biodiesel blends because of nanoparticles' ability to improve the combustion and thus improve the BTHE of the engine. Antioxidants blended with biodiesel decrease EGT because antioxidants act as a deterrent in the fuel reaction.

4.2. Emission results

The reasons for generating CO emissions of a diesel engine were low flame temperature, lower injection pressure, and too rich fuel–air ratio. Higher CO emissions may cause increased power losses of a diesel engine. Different factors for producing CO emissions are too high (or) too lean equivalence ratio and insufficient residence time. The CO emissions can be reduced by blending biodiesel with diesel fuel, which increases the oxygen concentration during the combustion, resulting in increased CO oxidation. The CO

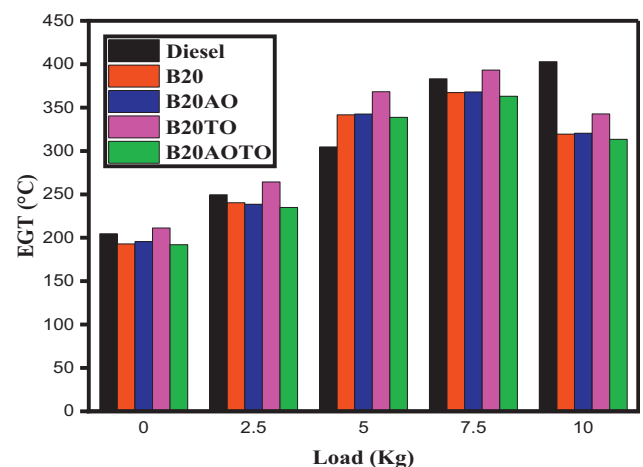
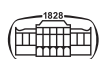


Fig. 4. Exhaust Gas Temperature (EGT) vs. load



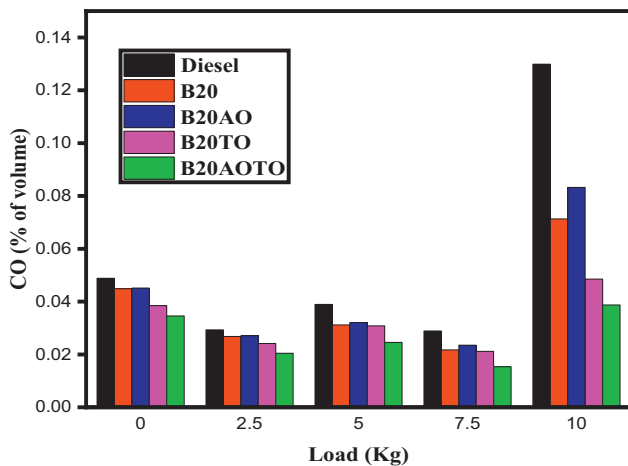


Fig. 5. Carbon Monoxide (CO) vs. load

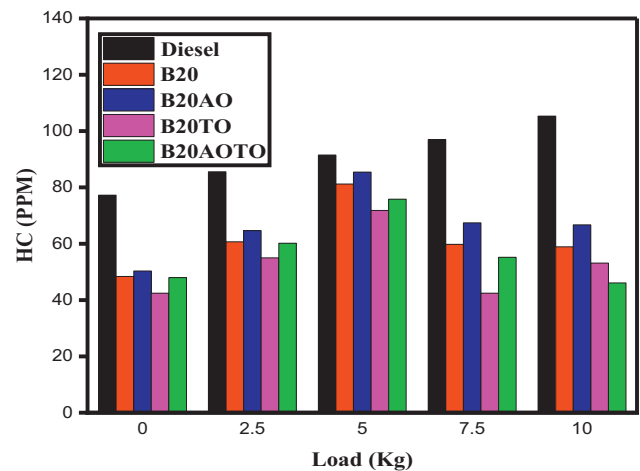


Fig. 6. Hydrocarbons (HC) vs. load

emissions of tested blends vary in load, as illustrated in Fig. 5. Diesel engines release lower levels of CO emissions, and it further reduces by using biodiesel as a fuel. Biodiesel contains oxygen molecules in their chemical composition, so it promotes complete combustion, thus leading to diminishing CO emissions. The other factor of reduced CO emissions was high CN and oxygen (O_2) molecules in biodiesel that give complete combustion of fuel. B20AOTO blend generated low CO emissions when compared with other blends. Nanoparticles blended with biodiesel ensured to reduce CO emissions because it further increased the oxygen content of fuel blend, and it has advanced ignition characteristics resulting in catalytic activity. The CO emissions increased by adding antioxidants to biodiesel, as illustrated in Fig. 5. The primary reason for increasing CO emissions is due to incomplete combustion resulting from the addition of antioxidant additives.

The primary causes for the production of HC emissions are incomplete flame propagation, the composition of the too lean or rich mixture, low injection pressure, and lower charge temperature. Diesel engines emit $1/5^{\text{th}}$ lesser HC emissions as correlated to petrol engines due to lean equivalence ratio. The HC emissions from tested blends vary in load, as illustrated in Fig. 6. The HC emissions increase with the increase of load on CI engine in all cases. HC emissions reduced by biodiesel fuel because it contains oxygen molecules, which ensure complete combustion and also due to the high CN of biodiesel, which often comprises oxygen molecules that contribute to complete combustion. The B20AOTO blend produced low HC emissions when compared with other blends. Nanoparticles blended with biodiesel ensured to reduce HC emissions because it further increased the oxygen content of fuel blend, and high surface to volume ratio of nanoparticles. The HC emissions increased by adding antioxidants to biodiesel, as illustrated in Fig. 6. The primary reason for increasing HC emissions is due to the reduction of the formation of free radicals resulting from the addition of antioxidant additives.

The production of NO_x emissions depends on volumetric efficiency, combustion duration, and high combustion

temperature for the high energy activation required for the reactions involved. Biodiesel combustion produces higher emissions of NO_x than diesel due to its rich oxygen content, which causes the fuel-rich areas to respond to oxidation at high combustion temperatures, and it leads to the formation of NO_x emissions. Figure 7, B20 fuel showed high NO_x emissions when contrasted with diesel. The principle reason for increasing NO_x emissions is biodiesel's molecular structure and the formation of CH radicals. Various theories explained that the increased NO_x emissions are the advancement of fuel injection timing, the higher adiabatic flame temperature of biodiesel, more stoichiometric burning, larger spray droplet size, reduced radiation from soot particles, and fuel bound oxygen. The nitrogen molecule's strong triple covalent bond reacts to the free radical and ultimately forms NO_x emission by successive chemical responses. However, the B20AOTO blend showed fewer NO_x emissions contrasted with other blends. Metal oxide based nanoparticles blended with biodiesel as a fuel leading to complete combustion due to these acting as oxygen donating catalysts in the combustion chamber. During the combustion phase, the nanoparticles act as catalysts that reduce nitric oxide radicals to N_2 . Antioxidants act as a free radical quenching agent. Antioxidants blended with

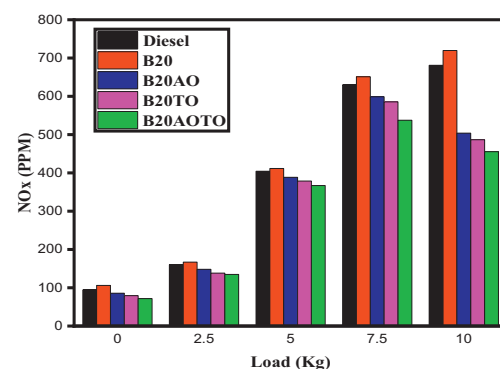


Fig. 7. Nitrogen Oxides (NO_x) vs. load

biodiesel produce fewer NO_x emissions as a result of reducing the formation of free radicals.

5. CONCLUSIONS

Adding NPPD antioxidant and TiO₂ nanoparticles to biodiesel blends improved the performance and emission parameters of the CI engine. Below are discussed the conclusions of the current research work.

B20 with additives showed lower BSFC when compared with B20 blends. Low BSFC was obtained with the use of the B20AOTO blend contrasted with other B20 blends. At maximum load, it was almost equal to diesel fuel. Biodiesel contributed high BTHE contrasted with diesel because of the high CN and O₂ molecules present in biodiesel composition. Further, BTHE increases by blending antioxidants and nanoparticles with a B20 blend. At full load, B20AOTO showed high BTHE when contrasted with other blends. B20AOTO blend showed less EGT as compared to other tested fuel blends at high load. Nanoparticles blended with biodiesel exhibit higher EGT compared to different biodiesel blends because of nanoparticles' ability to improve the combustion and thus improve the BTHE of the engine. Antioxidants blended with biodiesel decrease EGT because antioxidants act as a deterrent in the fuel reaction.

B20AOTO blend showed low HC and CO emissions when compared with other blends. Biodiesel consists of high CN, and the presence of oxygen molecules produces a complete combustion of fuel. B20 blends raise NO_x emissions to 10% correlated to diesel. B20AOTO blend showed fewer NO_x emissions contrasted with other blends. This investigation concluded that the B20AOTO blend showed optimum performance and emission parameters when compared with other blends.

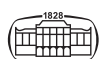
NOMENCLATURE

Al ₂ O ₃	aluminium oxide
ASTM	american society for testing and materials
BHT	butylated hydroxytoluene
BTHE	brake thermal efficiency
BSFC	brake specific fuel consumption
BHA	butylated hydroxyanisole
B0	100% Diesel + 0% Biodiesel
B20	80% Diesel + 20% Biodiesel
B30	70% Diesel + 30% Biodiesel
B50	50% Diesel + 50% Biodiesel
B20A0	80% Diesel + 20% Biodiesel + 1500 PPM NPPD antioxidant
B20T0	80% Diesel + 20% Biodiesel + 60 PPM TiO ₂ nanoparticles
B20AOTO	80% Diesel + 20% Biodiesel + 1500 PPM NPPD antioxidant + 60 PPM TiO ₂ nanoparticles

CN	cetane number
CV	calorific value
CO ₂	carbon dioxide
CO	carbon monoxide
DI	direct injection
CI	compression ignition
DAS	data acquisition system
DTBP	di-tert-butyl peroxide
DEA	di-Ethyl Amine
EGT	exhaust gas temperature
GSBD	grape seed oil methyl ester
GSBDZnO100	grape seed oil methyl ester + 100 ppm zinc oxide nanoparticles
HC	hydrocarbons
HOME	honge oil methyl ester
HOME50Graphene	honge oil methyl ester + 50 ppm graphene
JBD25A25CNT	Jatropha biodiesel + 25 ppm aluminum oxide + 25 ppm carbon nanotubes
NO _x	nitrogen oxides
NPPD	N-phenyl-1,4-phenylenediamine
NPAA	4-Nonyl phenoxy acetic acid
N ₂	nitrogen
nm	nanometers
O ₂	oxygen
PHC	pyridoxine hydro-chloride
PPM	parts per million
POME	palm oil methyl ester
PrG	propyl gallate
PM	particulate matter
PPDA	P-Phenylenediamine
SO ₂	sulfur dioxide
TiO ₂	titanium oxide
TBHQ	tert butyl hydro quinone
VCR	variable compression ratio

REFERENCES

- [1] V. B. Chaudhari, S. U. Patel, and D. S. Dhaval Sodha, "Performance & emission of C.I engine using neem- biodiesel with additives," *Int. J. Scientific Res.*, vol. 3, no. 4, pp. 164–6, 2012.
- [2] R. D. Misra and M. S. Murthy, "Blending of additives with biodiesels to improve the cold flow properties, combustion, and emission performance in a compression ignition engine—A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 5, pp. 2413–22, 2011.
- [3] A. H. Demirbas and I. Demirbas, "Importance of rural bioenergy for developing countries," *Energy Convers. Manag.*, vol. 48, no. 8, pp. 2386–98, 2007.
- [4] S. M. A. Rahman, H. H. Masjuki, M. A. Kalam, M. J. Abedin, A. Sanjid, and H. Sajjad, "Impact of idling on fuel consumption and exhaust emissions and available idle-reduction technologies for diesel vehicles – A review," *Energy Convers. Manag.*, vol. 74, pp. 171–82, 2013.



- [5] A. M. Ashraful, H. H. Masjuki, M. A. Kalam, I. M. Rizwanul Fattah, S. Imtenan, S. A. Shahir, and H. M. Mobarak, "Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: A review," *Energy Convers. Manag.*, vol. 80, pp. 202–28, 2014.
- [6] A. S. Silitonga, H. H. Masjuki, T. M. I. Mahlia, H. C. Ong, W. T. Chong, and M. H. Boosroh, "Overview properties of biodiesel-diesel blends from the edible and non-edible feedstock," *Renew. Sustain. Energy Rev.*, vol. 22, pp. 346–60, 2013.
- [7] S. K. Hoekman, A. Broch, C. Robbins, E. Ceniceros, and M. Natarajan, "Review of biodiesel composition, properties, and specifications," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 143–69, 2012.
- [8] W. N. M. Wan Ghazali, R. Mamat, H. H. Masjuki, and G. Najafi, "Effects of biodiesel from different feedstocks on engine performance and emissions: a review," *Renew. Sustain. Energy Rev.*, vol. 51, pp. 585–602, 2015.
- [9] A. Bai, P. Jobbagy, F. Farkas, J. Popp, G. Grasselli, J. Szendrei, and P. Balogh, "Technical and environmental effects of biodiesel use in local public transport," *Transport. Res. Part D: Transport and Environ.*, vol. 47, pp. 323–35, 2016.
- [10] M. I. Mahmud and H. M. Cho, "A review on characteristics, advantages and limitations of palm oil biofuel," *Int. J. Glob. Warming*, vol. 14, no. 1, pp. 81–96, 2018.
- [11] J. B. Hirkude and A. S. Pdalkar, "Performance and emission analysis of a compression ignition engine operated on waste fried oil methylesters," *Appl. Energy*, vol. 90, no. 1, pp. 68–72, 2012.
- [12] Z. M. Hasib, J. Hossain, S. Biswas, and A. Islam, "Bio diesel from mustard oil: A Renewable alternative fuel for small diesel engines," *Mod. Mech. Eng.*, vol. 1, no. 2, pp. 77–83, 2011.
- [13] S. Simsek, "Effects of biodiesel obtained from Canola, sefflower oils and waste oils on the engine performance and exhaust emissions," *Fuel*, vol. 265, p. 117026, 2020.
- [14] S. M. A. Rahman, H. H. Masjuki, M. A. Kalam, M. J. Abedin, A. Sanjid, and M. M. Rahman, "Assessing idling effects on a compression ignition engine fuelled with *Jatropha* and Palm biodiesel blends," *Renew. Energy*, vol. 68, pp. 644–50, 2014.
- [15] J. S. Basha and R. B. Anand, "Performance and emission characteristics of a DI compression ignition engine using carbon nanotubes blended diesel," *Int. J. Adv. Therm. Sci. Eng.*, vol. 1, no. 1, pp. 67–76, 2010.
- [16] V. A. Bhagwat, C. Pawar, and N. R. Banapurmath, "Graphene nanoparticle-biodiesel blended diesel engine," *Int. J. Eng. Res. Technol.*, vol. 4, no. 2, pp. 75–8, 2015.
- [17] V. Praveena, M. L. J. Martin, and V. E. Geo, "Experimental characterization of CI engine performance, combustion and emission parameters using various metal oxide nanoemulsion of grapeseed oil methyl ester," *J. Therm. Anal. Calorim.*, vol. 139, pp. 3441–56, 2020.
- [18] A. I. El-Seesy, A. M. A. Attia, and H. M. El-Batsh, "The effect of Aluminum oxide nanoparticles addition with *Jobba* methyl ester-diesel fuel blend on a diesel engine performance, combustion and emission characteristics," *Fuel*, vol. 224, pp. 147–66, 2018.
- [19] V. Dhana Raju, P. S. Kishore, K. Nanthagopal, and B. Ashok, "An experimental study on the effect of nanoparticles with novel tamarind seed methyl ester for diesel engine applications," *Energy Convers. Manag.*, vol. 164, pp. 655–66, 2018.
- [20] M. M. Musthafa, T. A. Kumar, T. Mohanraj, and R. Chandramouli, "A comparative study on performance, combustion and emission characteristics of diesel engine fuelled by biodiesel blends with and without an additive," *Fuel*, vol. 225, pp. 343–8, 2018.
- [21] S. Rajendran, "Effect of antioxidant additives on oxides of nitrogen (NO_x) emission reduction from *Annona* biodiesel operated diesel engine," *Renew. Energy*, vol. 148, pp. 1321–6, 2020.
- [22] C. Dueso, M. Munoz, F. Moreno, J. Arroyo, N. Gil-Lalaguna, A. Bautista, A. Gonzalo, and J. L. Sanchez, "Performance and emissions of a diesel engine using sunflower biodiesel with a renewable antioxidant additive from bio-oil," *Fuel*, vol. 234, pp. 276–85, 2018.
- [23] B. Ashok, K. Nanthagopal, A. K. Jeevanantham, P. Bhowmick, D. Malhotra, and P. Agarwal, "An assessment of *calophyllum inophyllum* biodiesel fuelled diesel engine characteristics using novel antioxidant additives," *Energy Convers. Manag.*, vol. 148, pp. 935–43, 2017.
- [24] K. Velmurugan and A. P. Sathiyagnanam, "Impact of antioxidants on NO_x emissions from a mango seed biodiesel powered diesel engine," *Alexandria Eng. J.*, vol. 55, no. 1, pp. 715–22, 2016.
- [25] R. Kyunghyum, "The characteristics of performance and exhaust emissions of a diesel engine using a biodiesel with antioxidants," *Bioresour. Technol.*, vol. 101, pp. S78–82, 2010.
- [26] M. A. Kalam and H. H. Masjuki, "Testing palm biodiesel and NPAA additives to control NO_x and CO while improving efficiency in diesel engines," *Bio Mass and Bio Energy*, vol. 32, pp. 1116–22, 2008.

