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The Influence of Different Nanoparticles Incorporated Fuel Blend on Diesel Engine Performance and Emission Characteristics

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Abstract

Diesel engines are the key source of prime movers for our society. However, the emissions emanating from the consumption of diesel fuel in the diesel engine causes severe effects on the environment and living beings. In view of this, the present study aims to reduce exhaust emissions with the help of biodiesel and different nano additives. The canola biodiesel has been prepared for the present study by transesterification process, and the percentage of biodiesel added to the diesel fuel is 30% by volume. Nano additives such as Al_2O_3 and TiO_2 were used as additives to fuel blends. The concentration of each (Al_2O_3 and TiO_2) nanoparticles varied in the fuel blend is 50ppm and 100ppm. A single cylinder water cooled diesel engine was employed for the study. The constant injection pressure and compression ratio is maintained by 240bar and 16.5. The load on the engine varied by 25% to 100% in the steps of 25. From the results, it was observed that the addition of nano additives improves the BTE and reduces the BSFC of the engine. The emissions of NOx, CO, HC and smoke were reduced significantly for nano additive fuel blends compared to diesel fuel. The results revealed that nanoparticles with 100ppm blended fuels showed improved engine working characteristics compared with other fuel blends. It was also noticed that Al_2O_3 nanoparticles blended fuel showed better performance compared to TiO_2 nanoparticles fuel blend.

Keywords: Diesel engine, Canola biodiesel, Al_2O_3 nanoparticles, TiO_2 nanoparticles, engine characteristics.

1. Introduction

A country's economic development is mainly dependent on its supply of energy. Most of the energy needs of the country are satisfied with petroleum-based fuels. Demand for petroleum-based fuels has risen sharply, and with it, the price of those fuels is increasing highly. In a developing country like India, the transportation and agricultural sectors rely heavily on fossil fuels. To meet energy needs, efficient use of natural resources is essential. Alternative fuels are becoming increasingly important in today's world because of the scarcity of fossil fuels, the rising price of petroleum fuels, domestic production, and growing environmental alarms [1-5]. Edible oil fuels are better alternatives for replacing diesel. Vegetable oils have the advantage of being biodegradable and domestically produced, which reduces the need for petroleum-based fuel imports. Edible oils have similar properties to diesel, and they also have a high cetane number and the presence of oxygen (O_2) molecules in their composition. It enhances combustion due to the presence of O_2 molecules in biofuels. Despite their advantages, they have poor cold flow characteristics, a higher viscosity, a lower calorific value (CV). As a result of the higher viscosity of edible oils, larger fuel droplets are produced, resulting in carbon deposits in the cylinder liner and the injector nozzle, resulting from incomplete combustion [6-13].

Various biodiesel fuels have recently been developed from edible oils, including soybean, canola, sunflower, and palm. According to various works of literature, transesterification is the best method for producing biodiesel. Canola oil has low saturates percentages and high oleic acid content, among other vegetable oils. Due to this, it has high combustion stability and produces fewer exhaust emissions. Some of the works discussed below use biodiesel as fuel on a diesel engine. Ceikten et al. [14] studied rapeseed and soybean biodiesel fuels at a CI engine's full load. At all injection pressures, biodiesel blends produced less torque and power than diesel. Soybean biodiesel has the higher BSFC of the fuels tested. CO and smoke emissions are lower, but NOx emissions are higher compared to the other test fuels. Rapeseed biodiesel behaves similarly to the other test fuels. The linseed methyl ester was used by Puhan et al. [15] to investigate the effect on an engine's working characteristics. It has been demonstrated that linseed methyl esters BTE is the same as diesel, but biodiesel blends reduced CO, HC, and smoke emissions compared to conventional fuel. However, it increased NOx emissions. Cenk Sayin et al. [16] investigated the effects of injection pressure on a diesel engine fuelled with biodiesel blends. The obtained results showed high BSFC, Low BTE, and less CO, HC emissions but raised NOx emissions by increasing the concentration of biodiesel. While increasing IP, enhance the performance characteristics of an engine. Increases in IP resulted in lower CO, HC, and smoke emissions while increasing NOx emissions for other tested fuels.

Metin Gumus et al. [17] used biodiesel blends as fuel to investigate the effect on a diesel engine. Biodiesel blends showed high BSFC and NOx emissions, while HC, CO, and smoke emissions decreased. Dinesha et al. [18] conducted the effects of a cardanol biofuel blend on the performance and emission characteristics of the CI engine. B20M10 test fuel blend composition is 70% diesel, 10% methanol and 20% cardanol. According to the results, the optimal fuel IP with B20M10 is 220 bars. With the B20M10 blend, a reduction in HC, CO, and smoke emissions was observed, whereas an increase in NOx emissions and BTE was noticed at the optimized pressure. Compared to diesel, the B20M10 blend at 220 bar IP results in lower BTE and lower HC and CO emissions but slightly higher NOx and smoke emissions.

Various additives were used to address the key biodiesel difficulties of lower CV, high BSFC, low oxidation stability, and high NOx emissions than diesel. Biodiesel's drawbacks have been overcome by nanoparticle additives, which reduce emissions to acceptable levels. The catalytic activity and surface-to-volume ratio of nanoparticles are extremely high. Therefore, diesel engines' performance and emissions are improved. Using zinc oxide nanoemulsion and biodiesel, Praveena et al. [17] investigated the effects of nanoparticles blended with biodiesel as fuelled on a CI engine. By using GSBDZnO100, the results showed a slight increase in the BTE, but it also reduced NOx emissions by 10.8%, 13%, and 4.6%, respectively (GSBD). By blending Al_2O_3 nanoparticles with jojoba biodiesel, El-Seesy et al. [18] studied CI engine performance and emissions. The results revealed that biodiesel blended with nanoparticles reduced BSFC by 12% compared to biodiesel. Also reduced HC by 60%, CO by 80%, and smoke opacity by 35% compared to biodiesel. Dhana Raju et al. [19] studied the effects of tamarind seed methyl ester blended with Al_2O_3 nanoparticles as a fuel on a CI engine. The obtained results revealed that using biodiesel with an additive increased BTHE while decreasing HC, CO, and NOx compared to using biodiesel. Vali et al. [22-24] studied different nanoparticles with various fuel blends on diesel engine working characteristics. From their results, it was observed that the performance and emission characteristics of the diesel engine were improved substantially. Reddy et al. [25] carried out experiments on diesel engines' performance and emission studies by adding TiO2 nanoparticles as an additive in biodiesel blends. The results showed high BTE and decreased BSFC and HC, CO and NOx emissions by using the B20 biodiesel blended with nanoparticles fuel blend contrasted with biodiesel blends.

The results of these studies demonstrate that biodiesel is beneficial in diesel engines. Although the effects of blending nanoparticles in the biodiesel blends, when injected at a higher pressure, on a diesel engine's performance and emission parameters are well understood, much work is still needed. According to the literature review, the Al_2O_3 and TiO_2 nanoparticles are low in cost and non-toxic compared to other nano-additives on the market. The experimental analysis uses canola biodiesel blends and Al_2O_3 and TiO_2 nanoparticles. The objective of the current study is to understand the effect of Al_2O_3 and TiO_2 nanoparticles blended canola biodiesel on diesel engine performance and emission characteristics.

2. Materials and methods

Super India Enterprises, India, supplied the canola oil. Diesel fuel was procured from a nearby city. The size of TiO_2 nanoparticles is in the range of 10-20nm, and Al_2O_3 is 30-50nm were purchased from a nano research lab. The characteristics of nanoparticles are provided in Table 1.

Table 1. Properties of nanoparticles

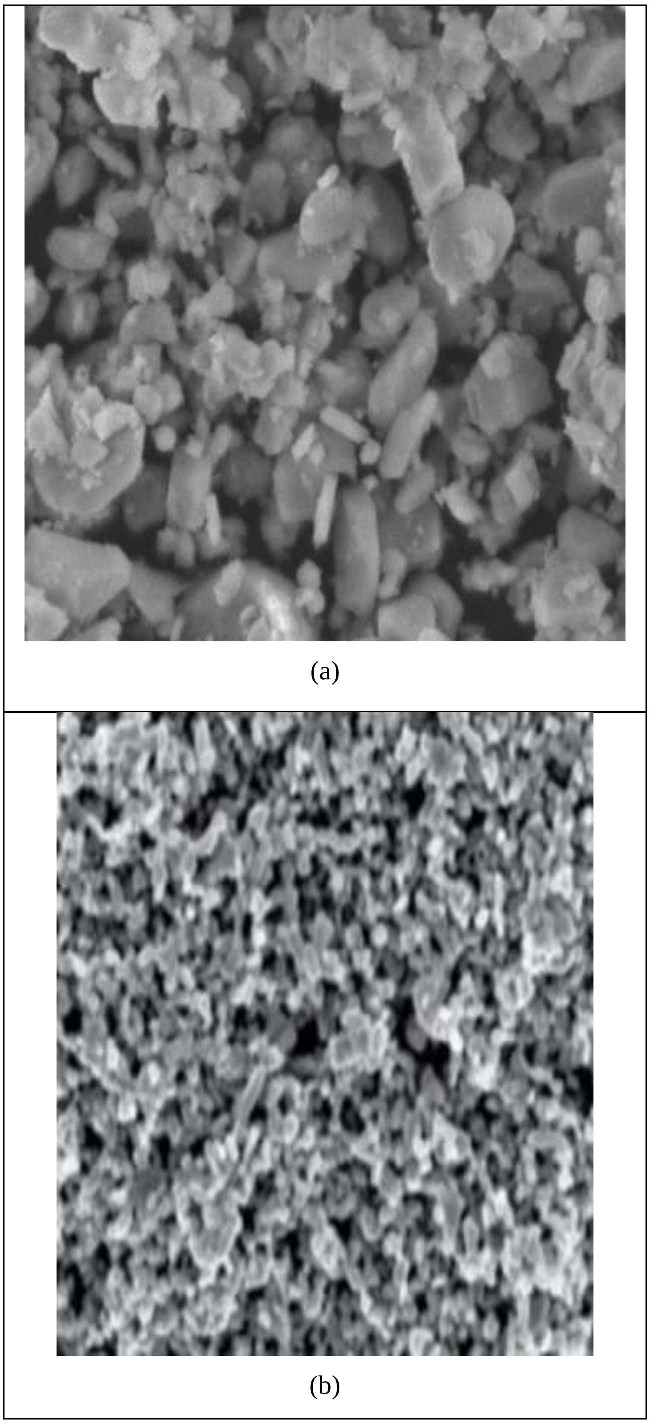
Item	Specifications	
Manufacturer	Nano Research Lab, India	Nano Research Lab, India
Molecular formula	Al_2O_3	TiO_2
Average particle size	30 – 50nm	10-20 nm
Color Appearance	White	White
Morphology	Spherical	Spherical
Purity	99.9%	99.9%
Bulk density	1.5 g/cm3	0.15-0.25 g/cm3
True density	3.97 g/cm3	4.23 g/cm3
Atomic Weight	101.96 g/mol	79.865 g/mol
Specific surface area SSA	120-140 m2/g	200-220 m2/g

2.1 Fuel blends preparation

The process of alkaline transesterification converts raw canola oil into canola oil methyl ester (COME). To make a methoxide solution, a sodium hydroxide of 1% volume was mixed in a methanol solution of 20% volume and agitated using a magnetic stirrer. With the help of an ultrasonicator, heated raw canola oil to 65°C, thereafter methoxide solution was mixed with the canola oil. The mixture was agitated for one hour, and the oil was separated into a separating funnel. With gravity, oil in a separating funnel settles into two layers after 24 hours. The upper portion of the separating funnel contained crude COME, while the lower contained glycerol. Now separate the crude COME from glycerol and thereafter wash with the water. Then crude COME heated up to 100°C to remove the water content in oil, and then obtained oil was clean COME.

2.2 Nanoparticle characterization and Blend preparation

This investigation used diesel-biodiesel blends with and without TiO_2 and Al_2O_3 nanoparticles as test fuel blends. Figure 1 depicts the results of scanning electron microscopy (SEM) tests that were carried out to determine the characterization of the Al_2O_3 and TiO_2 nanoparticles. The surface morphology and shape of Al_2O_3 and TiO_2 nanoparticles were determined using SEM. A magnetic stirrer was used to prepare different fuel blends containing various nanoparticles in the biodiesel-diesel blend. With their respective compositions, the different types of fuel blends are depicted in Table 2. The ASTM standard procedure was used to determine the properties of different fuel blends. The properties of various fuel blends are shown in Table 3.



(a)

(b)

Figure 1 SEM image of (a) Al_2O_3 (b) TiO_2

Table 2. Types of blends with composition

Blend Name	Composition
Diesel	0% Biodiesel + 100% Diesel
DB30	30% Biodiesel + 70% Diesel
DB30T50	30% Biodiesel + 69.95% Diesel + 50 PPM TiO_2 nanoparticles
DB30T100	30% Biodiesel + 69.9% Diesel + 100 PPM TiO_2 nanoparticles
DB30A50	30% Biodiesel + 69.95% Diesel + 50 PPM Al_2O_3 nanoparticles
DB30A100	30% Biodiesel + 69.9% Diesel + 100 PPM Al_2O_3 nanoparticles

Properties	Diesel	DB30	DB30 T50	DB30 T100	DB30 A50	DB30 A100
Density (kg/m^3)	825	845	845	847	846	848
Viscosity (mm^2/s)	3.40	3.60	3.62	3.65	3.62	3.66
Flash point (K)	324	345	347	351	346	350
Calorific value (MJ/kg)	43.2	41.2	41.3	41.9	41.5	42.1

Table 3. Properties of test fuels

3. Experimental setup

Figure 2 depicts a schematic representation of an experimental test setup. To load the diesel engine, a hydraulic dynamometer was employed. Table 4 lists the test rig's specifications. Several fuel measurement sensors, digital load sensors, and airflow rate sensors are integrated with the engine set up in a data acquisition system (DAS) configuration. Engine Soft software is employed to evaluate a diesel engine's performance parameters. HC, CO, and NOx emissions from the diesel engine have been evaluated with the help of a multi-gas emission analyzer. A smoke meter measures the amount of smoke exhausted from the diesel engine.

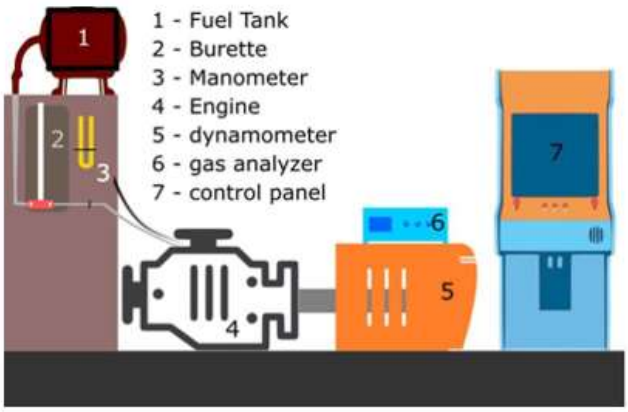


Figure 2. Schematic view of an experimental test rig

Table 4. Specifications of a test rig

Parameters	Specifications
Basic engine	Kirloskar
Model	Four stroke single cylinder water cooled VCR diesel engine
Make	TECH-ED
Stroke	110 mm
Connecting rod length	234mm
Bore	80 mm
Rated power	up to 4 KW
Compression ratio	16
Capacity	552cc
Injection Pressure	240 bar
Dynamometer	Hydraulic dynamometer
Speed	1500 rpm

4. Results and Discussions

The effect of fuel mixtures on engine performance and emission characteristics is explored in this section.

4.1 Brake Thermal Efficiency (BTE)

BTE evaluates how efficiently fuels chemical energy into work. Fig. 3 depicts the effect of different nanoparticles mixed diesel-canola biodiesel blend on diesel engine characteristics. From Fig. 3, increasing the load on the engine raises the BTE of the engine. The addition of biodiesel to diesel causes a slight reduction in the BTE of the engine because of lower heating value of fuel. The increase in BTE was noticed by inclusion of nanoparticles in the diesel-canola biodiesel blend. The amount of increase in BTE is proportionate to the percentage of nanoparticles in the fuel mixture. This is attributed to that nanoparticle have high surface to volume ratio and also high catalytic activity, which enhances the combustion attributes resulting in increased BTE. The fuel blend with 100ppm nanoparticles showed maximum BTE compared to 50ppm blend. The maximum BTE was found for the DB30A100 blend compared to all other blends. The increase in BTE for the DB30A100 blend compared to neat diesel is 4.55% and the DB30 blend is 10.03%.

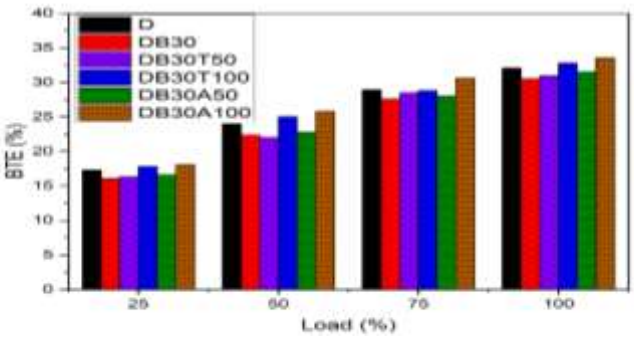


Fig. 3 BTE of various fuel blends with respect to load

4.2 Brake Specific Fuel Consumption (BSFC)

BSFC describes the amount of fuel consumed for unit power output. The BSFC of various fuel blends at different loads was depicted in Fig. 4. The reduction in BSFC has been noticed with increased load for all bleeds. This attributed to an increase in combustion temperature with increased load improves the combustion process resulting in reduced BSFC. The blending of canola biodiesel to diesel fuel causes a significant increase in the BSFC of the engine due to the lower calorific value of biodiesel fuel. It has also been noticed that the inclusion of nanoparticles in the diesel-biodiesel blend reduces the BSFC of engine. It is due to the higher surface area of nanoparticles increases the fuel oxidizer contact and improves the atomization resulting in lower BSFC. The higher heating value of nanoparticles fuel blends also helps to reduce BSFC of the engine. The DB30A100 blend showed lower BSFC in comparison to other fuel blends. The percentage of BSFC reduction for the DB30A100 blend is 5.93% and 10.19% compared to diesel fuel and DB30 blend.

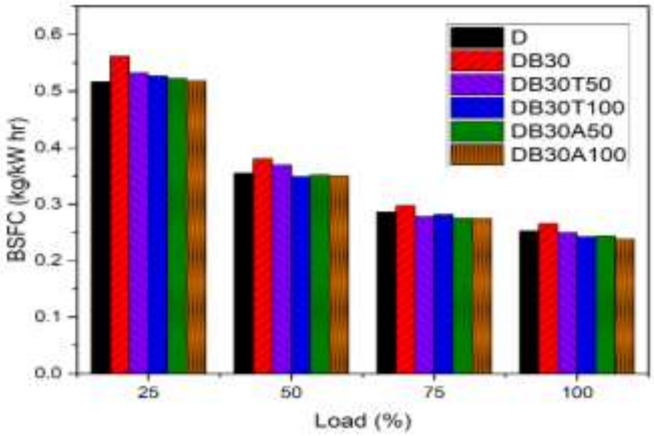


Fig. 4 BSFC of various fuel blends with respect to load

4.3 Carbon Monoxide emission (CO)

The formation of CO in the combustion chamber is due to the lack of oxygen and improper mixing. The emissions of CO increases with increased load, as illustrated in Fig. 5. At higher loads, more fuel is injected into the combustion chamber, causing a lack of oxygen availability, resulting in more CO. The CO emissions have been decreased with the addition of biodiesel to the diesel blend in contrast to diesel fuel. The decrease in CO emission is due to increased oxygen supply with the diesel-biodiesel blend. A further reduction in CO emission has been noticed by the inclusion of nanoparticles in the biodiesel-diesel blend. This is due to improved atomization, and catalytic activity of nanoparticles increases the oxidation resulting in increased conversion of CO into CO_2. The reduction in CO was found to be directly related to the volume fraction of nanoparticles in the fuel blends. The lower CO emission was observed for DB30T100 and DB30A100 blend compared to other blends and the percentage of reduction compared to diesel fuel is 11.63% and 13.95%.

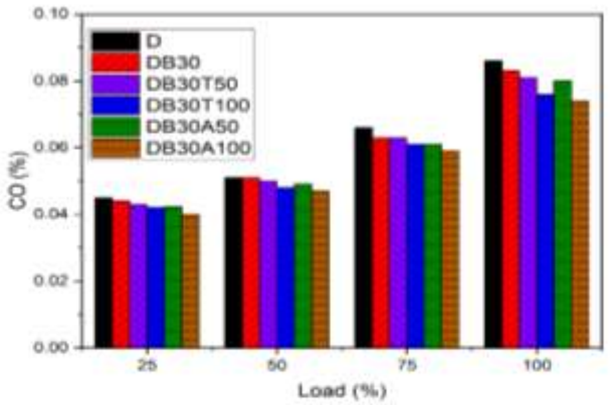


Fig. 5 CO of various fuel blends with respect to load

4.4 Hydrocarbon emission (HC)

The emissions of HC are mainly formed due to the partial combustion of hydrocarbons. The emissions of HC were increased with increased load for all fuel blends are depicted in Fig. 6. It has been found that adding biodiesel to diesel fuel reduces HC emissions. Because biodiesel consists of oxygen in their molecule structure, which improves the oxidation process resulting in the reduction in the formation of HC emission. The emission of HC formation is further decreased by adding nanoparticles to the diesel-biodiesel blend. It is attributed to nanoparticles acts as an oxidation catalyst, and also their higher surface area improves the fuel oxidizer contact, which enhances the oxidation process resulting in lower HC emission. In comparison to diesel fuel, the reduction in HC emission is 21.43% and 25% for the DB30T100 blend and DB30A100 blend. According to the findings, the DB30A100 blend produced less HC than other blended fuels.

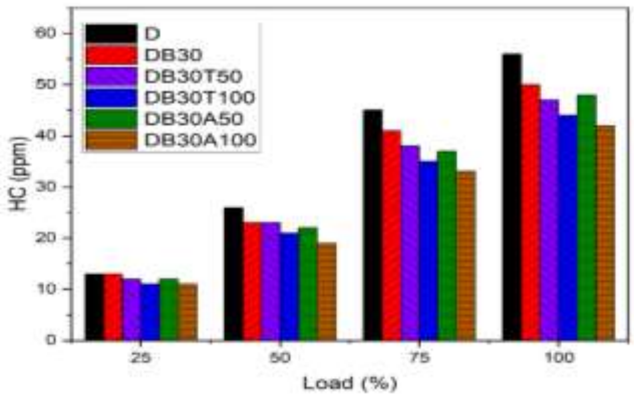


Fig. 6 HC of various fuel blends with respect to load

4.5 Oxides of Nitrogen emission (NOx)

The emissions of NOx generated from the diesel engine mainly depend on oxygen availability, combustion temperature and combustion duration. Fig. 7 describes the variation in NOx emissions for different fuel blends under various loads. The increased load increases the NOx emission and higher NOx was observed at higher loads. This is attributed due to higher combustion temperatures at higher loads. According to Fig.7, the addition of biodiesel enhances the generation of NOx. Because biodiesel increases the oxygen availability during the combustion and combustion duration compared to diesel fuel. The reduction in NOx emission was observed by inclusion of nanoparticles in the fuel blends. The reduction in NOx with nanoparticles fuel blend is because nanoparticle acts as reduction agent, which absorbs extra oxygen during combustion. The lower NOx was observed for 100ppm nanoparticles fuel blend compared to 50ppm nanoparticles fuel blend. The reduction in NOx emission for DB30T100 and DB30A100 fuel blends is 4.5% and 2.05% compared to diesel fuel.

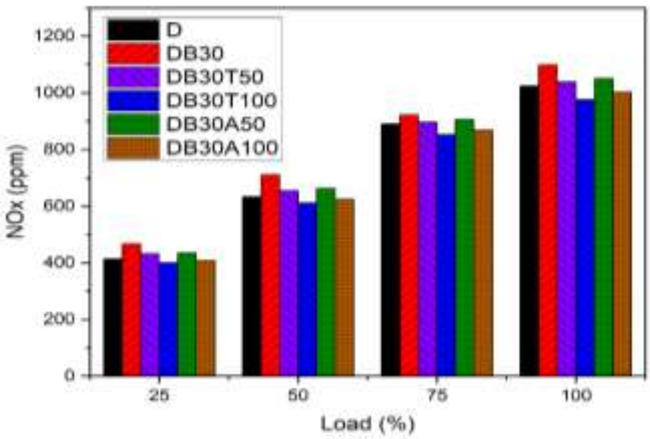


Fig. 7 NOx of various fuel blends with respect to load

4.6 Smoke emission

Smoke is mainly produced due to the rich fuel mixture supply and improper combustion. Fig.8 depicts the smoke emissions for different fuel blends under different loads. The increase in smoke emission was noticed with increased load for all fuel blends. At full load, the maximum smoke was emitted, which is due to rich mixture supply at high loads. The reduction in smoke emission has been observed with the addition of biodiesel. The reason for this is probably increased oxygen supply at the time of combustion with blended biodiesel fuel. The further reduction in emission of smoke was noticed with nanoparticle addition to the biodiesel-diesel blend. Because nanoparticles act oxidation catalyst which improves the oxidation process resulting in lower smoke emission. The increase in the concentration of nanoparticles decreases smoke emissions proportionally. Db30T100 and DB30A100 blend founds found lower smoke emissions compared to other blends. In comparison to the diesel and DB30 blend, the reduction in smoke emission for the DB30A100 blend is 17.75% and 9.41%.

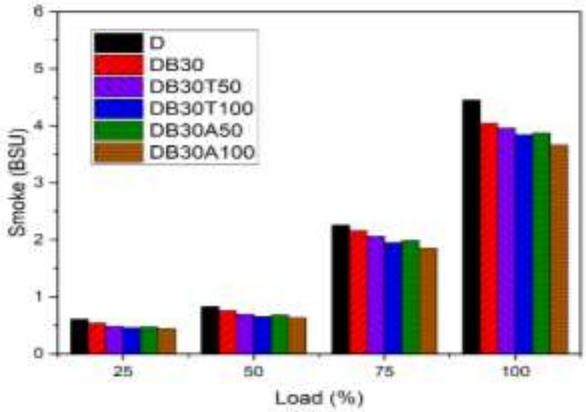


Fig. 8 Smoke of various fuel blends with respect to load

5. Conclusion

In the current study, the effect of different nano additives incorporated biodiesel blend on diesel engine performance, and emission parameters were investigated. Experiments have been conducted on a diesel engine with a constant speed of 1500 rpm under various loads. The performance parameters like BTE, BSFC and emission characteristics like HC, NOx, CO and smoke were evaluated for all fuel blends. The obtained results with nanoparticles fuel blends have been compared with neat diesel and the conclusions were summarized as follows.

- The BTE of the engine increased by 2.18% and 4.55% for DB30T100 and DB30A100 blends compared to diesel fuel.
- The reduction in BSFC was 4.35% and 5.93% compared to neat diesel for DB30T100 and DB30A100 blends.
- The CO emissions have been decreased by 11.63% and 13.95% for DB30T100 and DB30A100 blends compared to neat diesel.
- HC emissions were decreased by 21.43% and 25% in comparison to diesel fuel for DB30T100 and DB30A100 blends.
- Emissions of NOx and smoke were reduced by 4.5% and 13.71% for the DB30T100 blend and 20.5% and 17.75% for the DB30A100 blend in comparison to neat diesel fuel.

Overall, the DB30A100 blend showed improved performance and reduced emissions compared to other blends and diesel fuel.

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