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Performance, combustion, and emission characteristics of direct injection diesel engine fueled with ZnO dispersed canola oil biodiesel

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ABSTRACT

Diesel engines are critical to economic mobility. Because of the increasing scarcity of petroleum resources and the strict administrative rules, engine manufacturers and users must follow environmental regulations to avoid undesirable emissions. Vegetable oil could be used in diesel engines due to its high fluidity, poor stratification, ineffective ignition, and carbon buildup in the fuel system. The transesterification method reduces the viscosity of vegetable oil by converting it into methyl ester or ethyl ester, which is also known as biodiesel. This research examined the productivity, combustion, and output of zinc oxide nanoparticle disseminated canola oil biodiesel. The canola oil biodiesel was produced using the traditional transesterification process. The experimental hydrocarbons were produced using a magnetic agitator and ultrasonication, with a scattering of zinc oxide nanoparticles at a dosage of 50mg/l. The experiments were conducted at 1500 rpm. The use of zinc oxide nanoparticle dispersed canola oil biodiesel improved the specific fuel consumption, heat release rate, and other parameters. When compared to diesel, the brake thermal efficiency, nitrogen oxide, and hydrocarbon emissions were all lower. This study provides critical guidance on the use of sustainable energy, resulting in lower conventional oil consumption.

1. Introduction

Because of the rapid depletion of fossil fuels, alternative fuels have evolved. Biofuels are one of the potential fuels that may be used to lessen the reliance on conventional fuels. The use of conventional resources diminishes oil reserves at an astounding pace. According to poll estimates, natural resource consumption increased between 1990 and 2020, which was disastrous for the ecosystem.Research studies also mention the use of fuels derived from tallows to supplement or minimize diesel use[1]. Also, this can be a regenerative energy source that may be usedin a CI engine devoid of minor adjustments. Biodiesel overcomes the problems of higher fuel usage, reduced performance, higher NOx, and early initiation [9]. The primary remedies to such difficulties include altered energy, improved engine architecture, and post-treatment of combustion

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emissions [2]. Feed modification is an excellent technique for addressing the issues associated with the use of biodiesel in a powertrain using a cylindrical approach. This technique eliminates the high cost of deploying and maintaining effluent flow processing systems.Organic chemicals are used as additives in thefuel to alter their properties [4,24].Various fuel compounds, such as antioxidants, aerates, metal and metal oxides, cetane boosters, surfactants, and cold flow stimulants, are widely used as lubricant enhancers [10].The inclusion of a gasoline enhancer is cost-effective. Deposition, amalgamation, and non-uniform diameter are all issues associated with metal and metal oxide particulates. An NP smaller than 100 nm can be safely used as a diesel or biodiesel substitute in vehicles [24]. The addition of NPs to baseline propellant facilitates effective burning due to the enzymatic interaction of particulates with a larger contact surface [19]. Much research has beendone to analyze the influence of NPs in diesel mixtures on propellant properties, ignition, efficiency, and combustion properties in CI engines [12,16,19,3,5] scrutinized an oxygenation system involving latency inactivation, which resulted in lowered cylinder capacity. In a contrasting manner, the BTE and CO_2 output increased. Some research investigated various diesel cylinder variables under BD usage, which confirmed the compression enhancement within the combustion zone. There was a decrease in CO pollutants and an upsurge in NOx levels. The EGT also decreased owing to the decreased energy level of the fuel. Ranjan et al. (2018) investigated the effect of MgO NPs on the cold flow ability, effectiveness, and energy attributes of waste BD, establishing that NP inclusion improved various propellant characteristics. The SFC was greater for petroleum-based diesel (PBD), but the particulates were lower [7]. Combined Al_2O_3NPs with BD variants to assess the efficiency, burning, and pollution properties. They discovered that the inclusion of Al_2O_3 enhanced the effectiveness, burning, and pollutant minimization. Nevertheless, the desired discharge quality was obtained at a 20mg/l Al_2O_3level, whereas the efficiency and ignition were enhanced at 40 mg/l levels. Whenever combustion and efficiency were evaluated, a 30mg/l administration yielded better outcomes in all assessments. Some of the significant literature reviews are presented in Table 1.

Table. 1. Literature reviews.

No	Authors	Base fuel	Nano Particles	Result Discussion
1	Sivakumar et al.(2018)	Pongamia	Al_2O_3	Increase in BTE and decrease in BSFC
2	Soudagar et al. (2020)	Honge oil	Al_2O_3	BTE increased by 10.57 percent, while BSFC decreased.
3	Kumar et al., (2019)	Mahua oil	CeO_2	BTE improved and emissions decreased
4	Debnath et al. (2013)	Palm oil emulsion	----	Decrease in BSFC and NO_xdischarges
5	Selvaganapathy et al. (2013)	Diesel	ZnO	NO_x and BTE increased, while other pollutants decreased
6	Karthikeyan et al. (2014)	Pomolion stearin wax	ZnO	Increased BTE, EGT, and NO_x
7	Prabakaran et al. (2015)	Diesel ethanol mixtures	ZnO microscopic	Increase in HRR and BTE

According to the literature, efforts have been made to make neat biodiesel more feasible and effective. In this study, biodiesel was produced from canola oil. Its performance and emission characteristics were evaluated using a compression ignition engine; the effects of a nano-additive were also investigated. Based on the literature reviews, the effect of the additives on performance was investigated using 50mg/l proportions of ZnO nanofluid. The zinc oxide additives results were compared to the neat canola biodiesel and diesel.

2. Experimental setup

2.1. Materials and methods

2.1.1. Preparation of ZnO NPs

Table 2 shows the parameters of the ZnO nanoparticles. The ZnONPs were acquired from the marketplace, with a mean aggregate dimension of less than 50 nm in size. An ultrasonicator was used to blend the particulates continuously until homogeneity was achieved. An ultrasonicator is a tool that uses ultrasonic radiation for particulate dissemination. The NP level was taken as 50 mg/l. The ultrasonicator was of the sensor variety, with a capacity of 120 W and a wavelength ranging from 50 to 60 kHz.

Table. 2. ZnOnanoparticle specifications.

Chemical Formula	ZnO
Size	30nm
Purity	99.5%
Molecular weight	81.39g
Density at 25°C	5.6g/cm^3
Packaging	5g in poly bottle
Surface Area	10-15m^2/g
Colour	white

2.1.2. Preparation of canola oil biodiesel

In this investigation, plain canola oil was considered a potential replacement for diesel. The transesterification procedure enables the conversion of canola oil into methyl ester. The method entails the interaction of canola oil triglycerides with methyl alcohol in the presence of a sodium hydroxide agitator, yielding glycerol and fatty acid ester. Methyl alcoholis widely utilized because of various advantages. Alkali-catalyzed transesterification is more productive compared to the acid-catalyzed procedure. The appropriate proportions of canola oil (800 ml), methyl alcohol (200 ml), andsodium hydroxide (2 g) were used. Before initiating ester generation, the mixture was preheated to 70 °C and constantly stirred. Then it was left to remain for the night. As a result, a glycerol-based lower portion and an ester-based upper portion were formed. The attributes of the fuel are presented in Table 3.

2.1.3. Test fuel preparation

The variants were created by agitating the zinc oxide nanoparticles with COBD. Ultrasonication was used to prevent nanoparticle aggregation in the fuel blends [15,8]. The concentration of zinc oxide nanoparticles was set at 50mg/l. Initially, a 4:1 mixture of diesel with COBD was placed in a container and blended simultaneously using a magnetic agitator to create the B20 mix. It was agitated for 30 minutes before being ultrasonicated for 10 minutes [11]. Conventional diesel (D100), 100 percent COBD (B100), and 100 percent nanoparticle blended COBD (NB100) were employed in this investigation.

Table. 3. Properties of the fuels.

Sl.No	Property	Canola BD	Canola oil	Diesel fuel
1	Density (kg/m^3)	886.5	915	826
2	Kinematic viscosity (cS)	5.38	34	4.5
3	Cetane number	48	60	50
4	Heating value (kJ/kg)	38,758	39,500	42,800
5	Acid number (mg KOH/g)	0.01	1.4	0.01
6	Cloud point (^{0}C)	-6	-9	-6
7	Flash point (^{0}C)	172	315	50
8	Fire point (^{0}C)	186	371	56
9	Carbon residue (%)	0.54	0.03	0.1

2.1.4. Test engine setup

The experimentation arrangement is shown in Figure 1, and the variables are listed in Table 4. A mono-cylinder, 4S, Kirloskar CI engine was used. The experimental fuel was evaluated for burning, efficiency, and emission. The piston's movement volume was 662 ml, and the CR was 17.5:1. The fuel was supplied at a crank inclination of 23 degrees before TDC. The engine's operating speed and maximum power output were 1500 rpm and 4.4 kW, respectively.

An eddy current dynamometer was utilized. The cylinder pressure was determined using a Kistler piezoelectric pressure transducer. The pressure in the combustion chamber was recorded and acquired by an information collecting module for additional ignition investigation. The duration needed to use 10 ml of fuel was utilized. The voltage and current were used to calculate the efficiency parameters. An AVL DI GAS Gas Analyzer and a smoke meter were used to analyze the pollutants. Table 5 shows the equipment uncertainty rates. The expected numbers of uncertainty for a normal operating situation are shown below.

Table 4. Engine specifications.

Make and model	Kirloskar, Model TV1
Brake power	5.2kW
Speed	1500rpm
Compression ratio	17.5
Bore	87.5 mm
Stroke	110mm
capacity	661 ml
Ignition	CI
Cooling	water cooled
Loading system	Eddy current dynamometer
Combustion chamber	3 holes, 0.3mm diameter, spherical shape

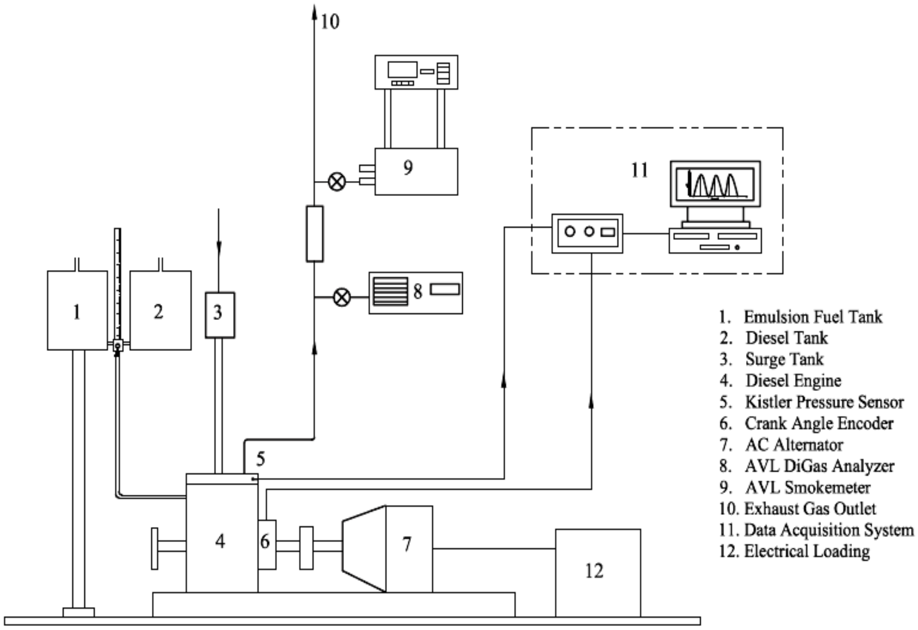

Fig. 1. Test Engine Layout.

3. Result and discussion

3.1. Performance characteristics

3.1.1. Brake thermal efficiency

Figure 2 depicts BTE differences with reference to load. The BTE of NB100 is smaller than that of diesel. The lower thermal efficiency of NB100 compared to diesel is due to lower calorific value, higher viscosity, and ineffective utilization of heat energy due to higher methyl ester molecular weight. Furthermore, at complete loading, the BTE of NP fuel is greater than that of canola fuel. The increase in thermal efficiency when B100 is mixed with a 50mg/l additive compared to B100 and diesel was due to the nanofluid's high oxygen content. As a result, it forms a homogeneous mixture and proper combustion occurs, resulting in higher thermal efficiency.

Table 8. Experimental uncertainties.

No	Quantity	Range	Accuracy	Uncertainty
1	AVL gas analyzer	NOx: 0–5000 mg/l	±10mg/l	±2.4
		HC 0–20,000 mg/l	±1 mg/l	±2.4
		CO 0–10 vol. %	±0.01%	±2.0
		CO_2 0–20 vol. %	±0.03%	±1.5
2	AVL smoke meter	0–100%	±0.2%	±2.1
3	Thermocouple	0–1000 °C	±1°C	±3
4	Speed measuring unit	0–5000 rpm	±10rpm	±1.2
5	Alternator	0–450 V, 0–20A	±1V,±0.5A	
6	In-cylinder pressure	0–110 bar	±0.5bar	±1.0
7	Crank angle encoder		±1 deg	

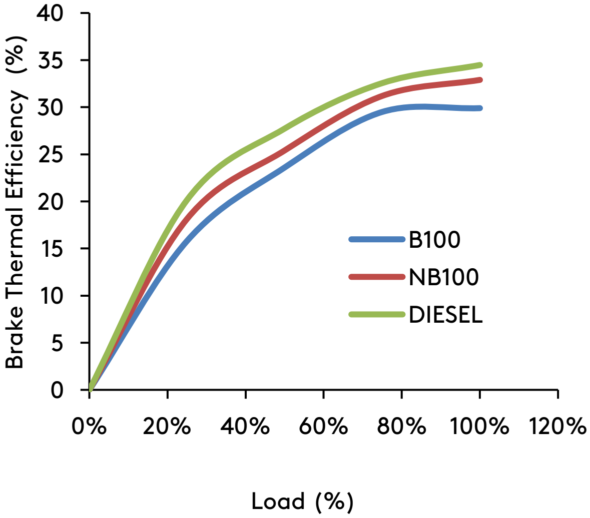

Fig.2. Brake thermal efficiency versus load for various test fuels.

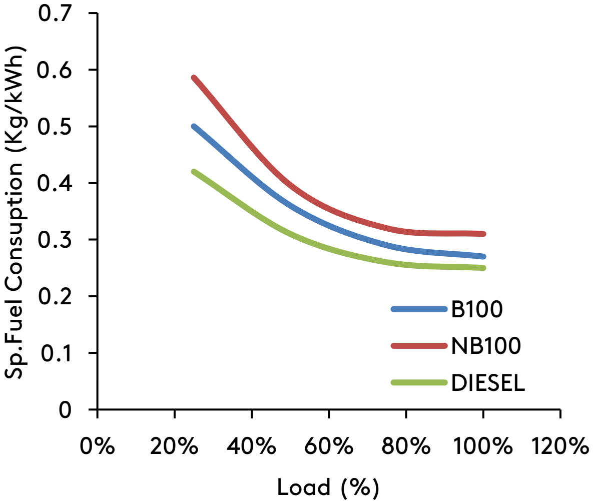

Fig. 3. Specific fuel consumption versus load for various test fuels.

3.1.2. Specific Fuel Consumption

Figure 3 depicts the SFC variation under various load combinations. The SFC is higher due to the lower calorie level of the variants than diesel. The heat of evaporation of the mixtures is high. Lower concentrations require more energy to vaporize, lowering the temperature of the burning area. Nonetheless, as the load increases, SFC decreases due to temperature increases at higher pressures. The ZnO NPs increase the burning rate through chemical activity, allowing better burning at high temperatures. Additionally, the surface-to-volume ratio of nanoparticles is increased, resulting in better alienation of blended fuels at high temperatures (Tewari 2013).

3.1.3. Exhaust gas temperature

Figure 4 depicts the fluctuation of EGT of the nanoparticle fuel vs diesel with regard to load. The EGT of the mixes is smaller than diesel. This is because ethanol-containing gasoline has a higher residual heat of vaporization. When the load augments, the exhaust gas temperature of the mixtures improves because of the mean temperature augmentation in the combustion area.As the vaporization of ethanol increases, the exhaust gas decreases. On the other hand, the addition of ZnO NPs accelerates burning due to enzymatic action, raising the mean temperature of the burning chamber.

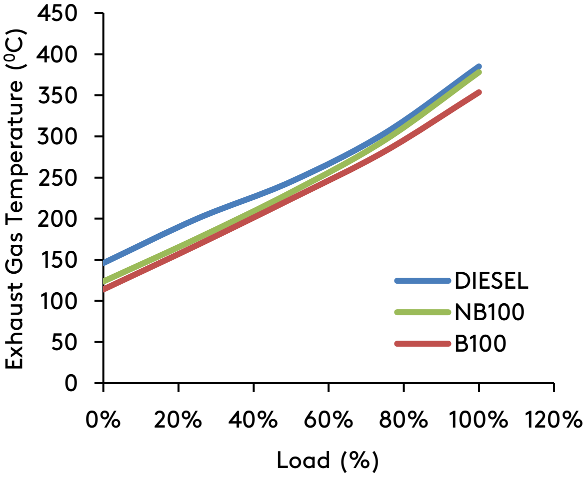

Fig. 4. Exhaust gas temperature versus load for various test fuels.

3.2. Emission characteristics

3.2.1. Hydrocarbons

Figure 5 depicts the variation of incomplete combustion HC concentrations in mixtures vs diesel under different loads. Lower cylinder temperature, deposits on the combustion chamber walls, non-stoichiometric air/fuel ratio, and incomplete combustion are the factors that greatly contribute to increased HC levels. Up to 75% loading, the HC of canola fuel is lower. Only at optimal capacity is it greater than diesel. This is due to the minimum duration for the combination to burn at maximum loading. Furthermore, the HC content of NP fuel is higher at lower capacities until 25% loading and lower after 25% loading than diesel. The reason is due to the interaction of micro particulates, which contributed to ignition improvement.

3.2.2. Carbon monoxide

Figure 6 depicts the variance of CO concentrations vs diesel in relation to the load. During partial loading, the CO of the canola mix is found to be greater than diesel. This is because the ethanol in the mix raises the heating of evaporation more than diesel, leading to worse alienation and chilling. This reduces the mean heating of the burning area, as indicated by the EGT at partial loading. Nonetheless, the heat-dominated evaporation decreases as the load increases, resulting in improved full combustion and lower CO discharge. At various intensities, the CO levels from the blended nanoparticle fuel are reduced compared to diesel. This is due to the presence of microscopic particles, which aid in combustion via enzymatic action, reducing CO pollution.

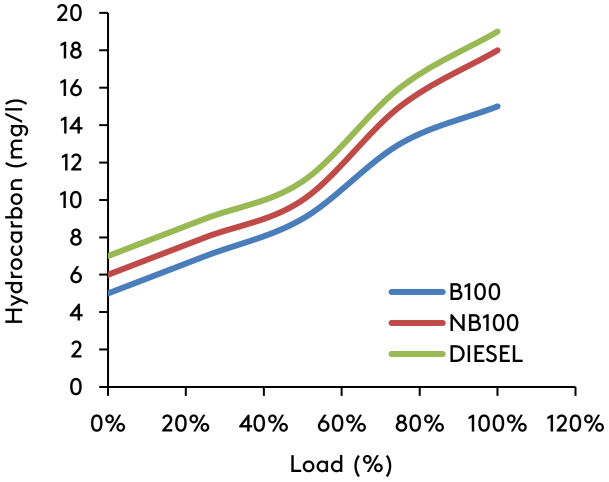

Fig.5. Hydrocarbons emissions versus load for various test fuels.

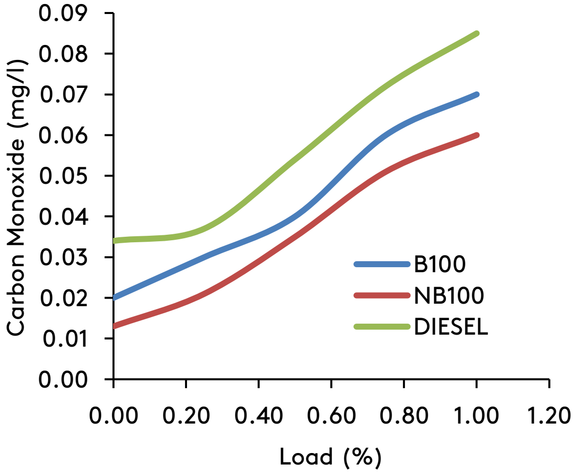

Fig.6. Carbon monoxide emissions versus load for various test fuels.

3.2.3. Oxides of nitrogen

Variations of NOx concentration of the various combinations are depicted in Figure 7. NOx emissions are due to higher combustion temperature, injection timing, lack of oxygen, and combustion quality. The NOx of the canola mix is lesser in all loading scenarios. The reason is due to ethanol availability, which lowers the mean ignition chamber temperature along with the prevention of NOx production. Furthermore, the combinations have reduced calorific content. The inclusion of ZnO in a canola biodiesel mix raises the calorific content and increases the mean burning chamber temperature. This results in higher NOx outputs compared to canola biodiesel and lowers NOx outputs compared to diesel.

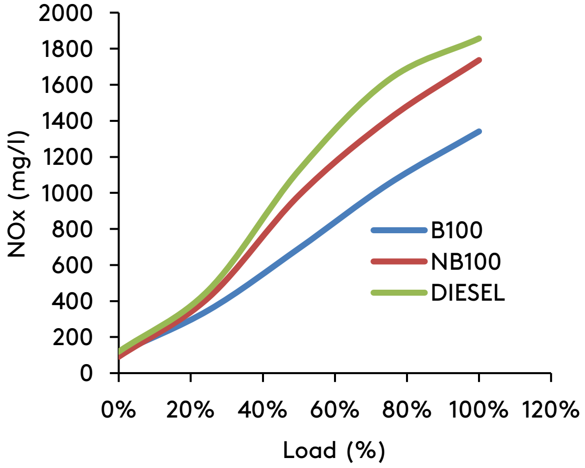

Fig.7. NOx emissions versus load for various test fuels.

3.2.4. *Smoke opacity*

Figure 8 depicts the fluctuation in smoke intensity of the NP fuel vs diesel with regard to load. The smoke produced by the canola mix is lesser than diesel. This might be ascribed to enhanced fuel burning in the combustion area. This is also consistent with past studies [1]. Additionally, the volatility of the fuel decreased, culminating in enhanced gasoline disintegration.

3.3. *Combustion characteristics*

3.3.1. *Cylinder pressure*

Figure 9 depicts the pressure variation of mixes at maximum loading regarding crank degree. At 0 CA, the highest pressure for diesel is 55.75 bar, 59.14 bar for canola mix, and 65.1 bar for NP fuel. The cylinder pressure of all mixes is higher due to quick-burning as a result of fuel concentration. This is due to the higher heat of evaporation of the fuel mixtures, resulting in reduced loading and increased accumulation.

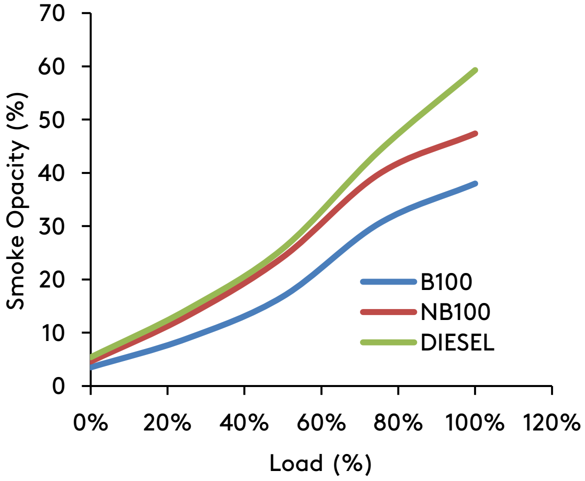

Fig.8. Smoke emissions versus load for various test fuels.

3.3.2. *Heat release rate*

Figure 10 depicts the heat release rate variations of combinations at full load to crank inclination. The maximal HRR is 44.25 kJ/m^3 deg at -4 deg CA, 48.92 kJ/m^3 deg for canola fuel, and 54.15 kJ/m^3 deg for NP fuel. The maximal heat output of the mixes is greater than diesel. This might be owing to superior burning characteristics as a result of the enhanced exterior area to the volume fraction of NPs. Increased O$_2$ fuel concentration; high momentum liquid droplets, increased injection velocity, and compression ratio are some of the other reasons.

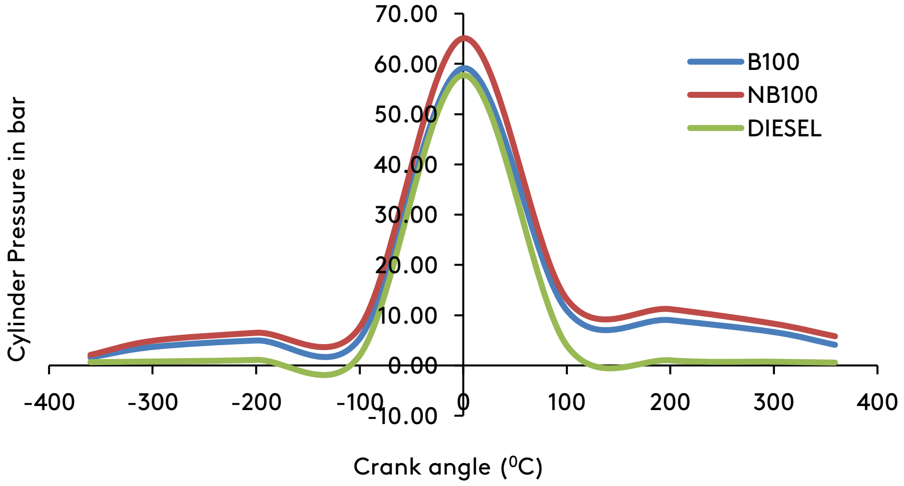

Fig.9. Cylinder pressure versus load for various test fuels.

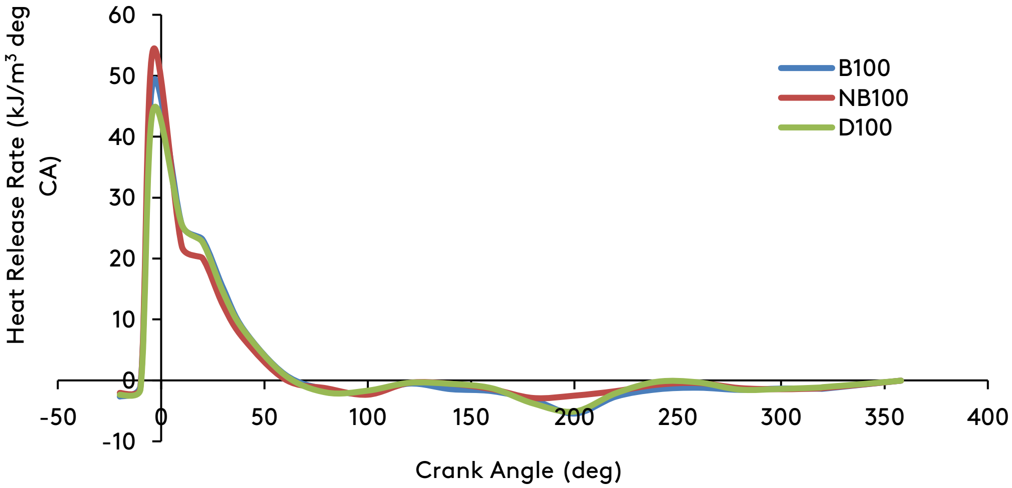

Fig.10. Heat release rate versus load for various test fuels.

4. Conclusions

Canola biodiesel was produced using both esterification and transesterification processes. The addition of zinc oxide nanoparticles to pure canola biodiesel was carried out using an ultrasonicator device. The performance and emission characteristics of a single-cylinder, 4-stroke, direct injection diesel engine with canola biodiesel were investigated and compared with neat diesel and canola biodiesel. The performance and emission of diesel engines were experimentally investigated at full load conditions using zinc oxide blended biodiesel with diesel fuel. The comments drawn from this learning were summarized as follows. It is observed that the brake thermal efficiency of the zinc oxide blended biodiesel (NB100) fuel is 4 % lower than diesel fuel and 13% lower than biodiesel at full load. The SFC values of zinc oxide blended biodiesel is 16% higher than diesel fuel. At various loads, HC emissions for all zinc oxide blended biodiesel is 5% lower. When compared to diesel fuel, the NOx emissions from zinc oxide blended biodiesel fuels were reduced by 7%. The 100% zinc oxide blended canola biodiesel had a 13% higher peak pressure and a 22% higher heat release rate than the other combinations.

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