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Impact of Al_2O_3 with Different Injection Pressures Using Deccan Hemp Oil Methyl Ester-Diesel Blend: An Experimental Study

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ABSTRACT

Fuel derived from deccen hemp oil (DHO) has been utilized in the current study due to non-stop consumption and unpredictable price fluctuations, which made researchers concentrate on searching for a suitable substitute for diesel fuel (DF). This study aims to investigate the effect of injection pressure (IP) on the performance, emission, and combustion behaviours of the compression ignition (CI) engine using aluminium oxide (Al_2O_3) nanoparticles. In the present work, the Al_2O_3 nanoparticles were blended with deccen hemp oil methyl ester-diesel fuel blend (DHME20) at a dosing level of 50 mg/l. Engine performance, emission, and combustion behaviour were assessed with Al_2O_3 blended DHME20 at two different IP of 210 and 230 bar, and results were analyzed. The blending of nanoparticles into the test fuel resulted in improved characteristics of the engine. Increased IP enhances the spray penetration in the cylinder, improving the combustion quality. This study concluded that mixing Al_2O_3 with DHME20 might be a better alternate fuel for a CI engine operating at 230 bar of IP.

1. Introduction

Rapid urbanization and rising living standards have increased the demand for energy in the agriculture, transportation, and power generation sectors [1–3]. The combustion of DF in a CI engine emits harmful emissions like oxides of nitrogen (NOx) and carbon monoxide (CO). The depletion of DF and the accomplishment of emission regulations worldwide have caused scientists, researchers, and automotive manufacturers to explore the best alternate fuel sources. One of the possible fuel resources used in IC engines is vegetable oil. Esterified vegetable oil (Biodiesel) can be utilized in CI (diesel) engines in its precise form with no engine hardware modification.Biodiesel is the best substitute for DF because it is non-toxic, easy to use, and biodegradable [4,5]. Unburnt hydrocarbons (HC), CO, NOx, and smoke can be reduced by utilizing biodiesel as an alternate fuel. Biodiesel can be mixed with DF at any concentrations. Several investigations have noticed that the blend B20 exhibits better results in all aspects [6,7].

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In India, the consumption of edible oils is higher than in many other countries. As a result, the Indian government promotes the utilization of non-edible oil seeds like jatropha, karanja, rubber seed, neem, caster, etc., to produce biodiesel [8]. In this work, DHO is selected for the synthesis of biodiesel. After conducting literature reviews on biodiesel, the author confirmed that DHO has not been widely investigated as a fuel option for CI engines. The Deccan hemp plant is scientifically known as *Hibiscus cannabinus*. It primarily thrives as a tropical crop, exhibiting its best growth in a humid climate with temperatures between 20^0C and 30^0C. The fertility of the soil has a major impact on the output of seeds and fibre. As the above-given temperatures are well suited to India, a large quantity is available in India. According to ICAR reports, India cultivates approximately 13.4 million metric tonnes of deccan hemp plants annually [9]. Hebbal *et al.,* [10] investigated the engine performance and exhaust emission behaviour of DHO in various concentrations in DF at different loads. Their findings reveal that the BSFC, BTE, and BSEC are well comparable with DF. The emissions of CO, HC, and Smoke of B50 are significantly higher than diesel by 71.42%, 33.3%, and 51.74%, respectively, at 100% load.

The blending of metal oxide (aluminium oxide, cerium oxide, and zinc oxide) nanoparticles into the biodiesel can improve the properties of the fuel [11–13]. Many properties of nanoparticles depend on their size [14–16]. Nanofluid is prepared by blending nanoparticles (less than 100 nm size) with a base fluid [17]. Hoseini *et al.,* [18] studied the influence of Graphene oxide nanoadditives on the emission and performance behaviour of a CI engine using *Ailanthus altissima* biodiesel diesel blends. They found that the bending of nanoadditives improved performance and emission results. Umit *et al.,* [19] investigated the impact of a waste cooking biodiesel blend (B10) with different metal oxide nanoparticles (Al_2O_3, TiO_2, and SiO_2) on the performance and emission phenomena of a CI engine. Their findings reveal that the blend B10 with Al_2O_3 exhibits higher BTE and lower BSFC than other nano blends (B10TiO_2 and B10SiO_2). Also, they recorded diminished CO, HC, and NOx for the B10Al_2O_3 blend compared to other blends. The addition of nanoparticles to biodiesel improves its physical properties due to the higher thermal conductivity of the nanoparticles [20]. Alex *et al.,* [21] studied the impact of cerium oxide nanoparticles in orange peel oil methyl ester on the engine characteristics of CI engine. They found a significant improvement in engine performance and a decline in harmful emissions such as HC and CO. Sachutananthan Baharathy *et al.,*[22] studied the engine performance fueled with plastic pyrolysis oil as an alternative fuel in a diesel engine with TiO_2 at various concentrations (25, 50, 75, and 100 ppm). The obtained findings reveal that the 50 ppm concentration in the plastic pyrolysis oil shows an increase in performance and a decrease in emissions such as HC, CO, and smoke. Sarsvan kumar *et al.,* [23] studied the influence of silicon dioxide nanoparticles on a diesel engine fueled with corn oil biodiesel. The obtained findings reveal that the addition of silicon dioxide nanoparticles has a positive impact on emission characteristics. Shaafi and Velraj [24] investigated the influence of Al_2O_3, ethanol, and iso-propanol as additives in biodiesel-DF blends to study engine behaviour. The study reports found that blending of Al_2O_3 and ethanol improved both heat release rate and cylinder pressure. Also, BTE, CO, and HC were decreased.

Extensive research were done on the blending of oxygenated alcohols (n-butanol [25], ethanol [26]) and carbon alcohols (n-pentanol [27], n-hexanol [28], and n-octanol [29]) with straight diesel and waste plastic oil [30]. The findings reveal that the inclusion of alcohol in fuel blends improves the viscosity of the blend and fuel atomization. Additionally, by making minor modifications in the CI engine parameter, the combustion and engine emission phenomena of the fuel blend findings are on par with straight diesel.

With a small modification of the operating parameters, it is possible to compare the attributes of an engine utilizing alternative fuel with conventional diesel. IP is one of the parameters that can be increased to get enhanced results due to its effect on atomization. Improved BTE was observed for mahua oil at 250 IP, and a decline in NOx was recorded at the same IP. In contrast, the combustion behaviour of *calophylum innophylum* was observed to be similar to compared to DF at 220 bar of IP [31, 32]. Murat [33] produced biodiesel by a 2-stage transesterification using waste cooking oil, and it was mixed with straight diesel in different concentrations (5, 10, 20, and 30%) to assess the impact of IP on CI engine characteristics. The author varied the IP from 170 to 210 bar with a step of 10 bar. However, biodiesel has a higher density and a lower heating value than pure diesel. The higher density of the biodiesel decreases the fuel spray characteristics.

To control this, he increased the IP for the blended fuels, which facilitates deep penetration in the cylinder and results in better atomization. These findings show an improvement in BTE, torque, peak cylinder pressure, NOx, and a decline in BSFC, HC, smoke, and CO of blended fuel up to an IP of 190 bar. Saravanan *et al.,* [34] utilized P30 blend as an alternate fuel, with various IP changing from 200 to 350 bar in a step of 50 bar. Obtained results reveal that the blend P30 exhibits good results at an IP of 350 bar. This combination achieves a higher BTE, a lower BSFC, and smoke. The blend P30 at 300 bar gave less emissions of CO and HC than P30 at 350 bar.

1.1 Novelty of The Present Work

A literature survey on biodiesel blends has shown the significant positive impact of nanoparticles on BTE and the diminishing of emissions. Furthermore, only a few research studies have been conducted on injection parameters. Also, no studies were found on the blending of metal oxide nanoadditives to the deccan hemp oil methyl ester blend to study the engine's behaviour. As per the author's knowledge, no past studies have reported the impact of Al_2O_3 nano blended DHME20 fuel on the behaviour of diesel engines operating at different injection pressures. Hence, the current paper is aimed to investing the combination effect of IP and Al_2O_3 nanoparticles in addition to determining the feasibility of utilizing DHME20 as a potential substitute for diesel in CI engines. Hence, this study investigates the combined effect of IP and Al_2O_3 nanoparticles in addition to determining the feasibility of utilizing DHME20 as a potential substitute for diesel in CI engines.

2. Materials and Methods

The methodology for the synthesis of deccan hemp oil methyl ester and engine testing is presented as a flow diagram in Figure 1. The steps are discussed in detail in the sections given below.

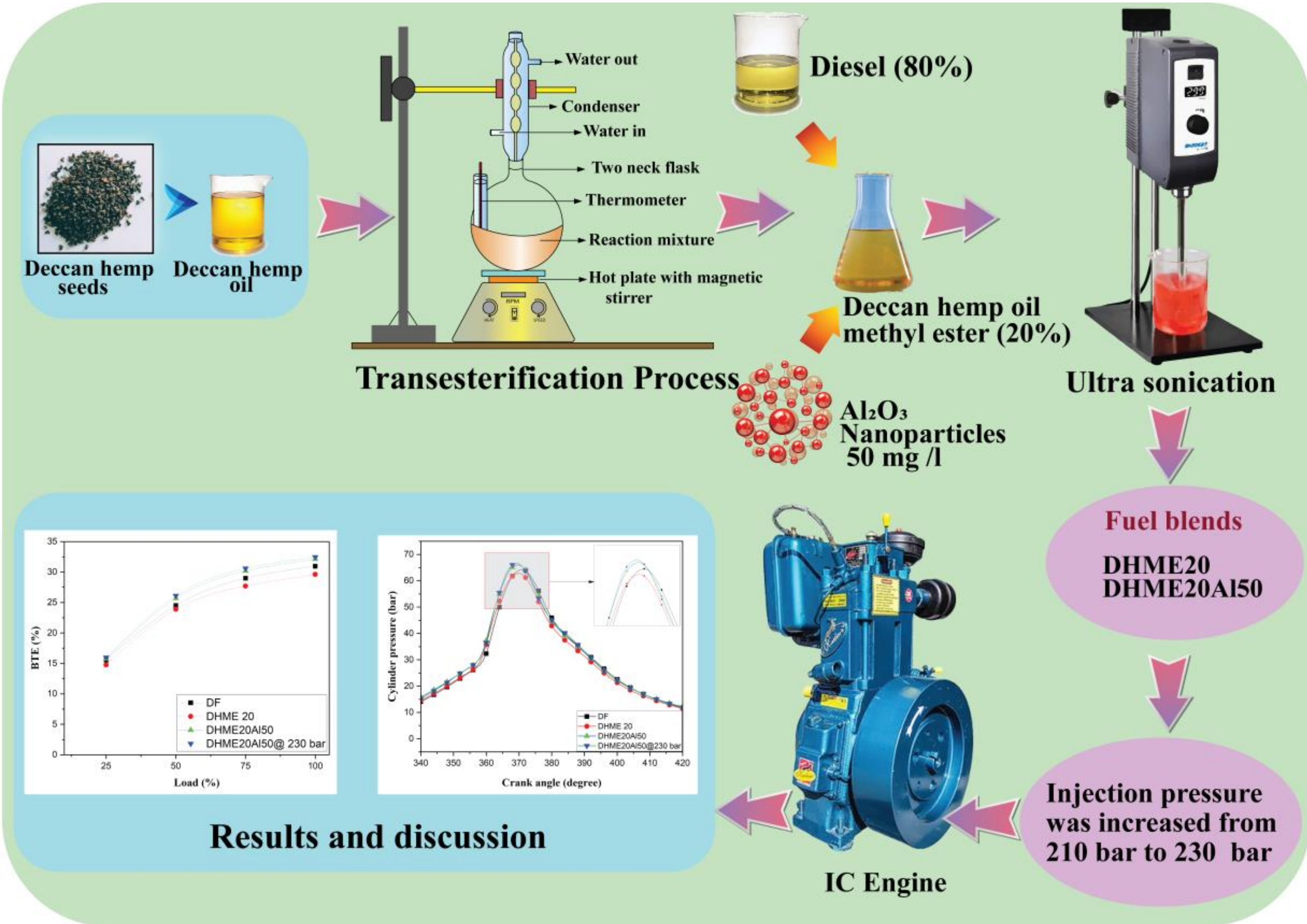

Fig. 1. Methodology adopted for the current study

2.1 Production of DHME

Deccan hemp seeds were procured from the local market in Bangalore, Karnataka. DHO was extracted by using a mechanical expeller. The oil contains a higher acid value (>2 mg KOH/g), as observed by titration. The two-stage acid esterification and transesterification processes were used to convert DHO oil into its methyl ester. A photographic view of the transesterification setup and results are depicted in Figure 2a and 2b. In the acid esterification stage, the raw DHO was treated with methanol and H_2SO_4 (0.75%) in the reactor. The reaction was done at 60^oC with a molar ratio of 9.5:1. After the reaction, the mixture was transferred to a funnel to settle for 2 hr. In the transesterification stage, the esterified oil was transferred to a reactor and heated up to 60^oC. Then, the CH_3ONa (0.42 wt%) and methanol (molar ratio of 6:1) mixture were added to it. The mixture was stirred at 850 rpm for 1hr. The mixture was permitted to settle overnight within a funnel. The top-separated DHME was gently washed using hot water and then heated up to 120^oC to remove excess water and methanol from it. In the current study, DHME was blended with straight diesel at a volume percentage of 20%, named DHME20.

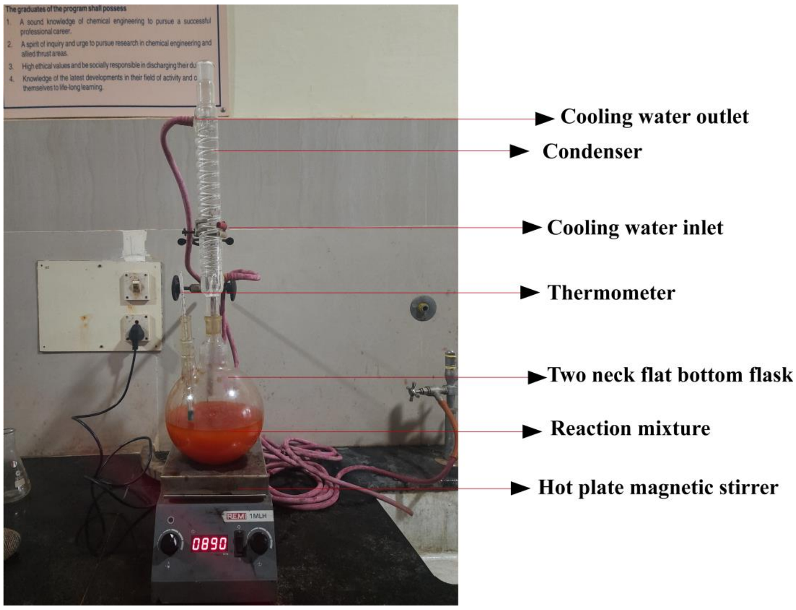

Fig. 2a. Photographic view of the transesterification setup

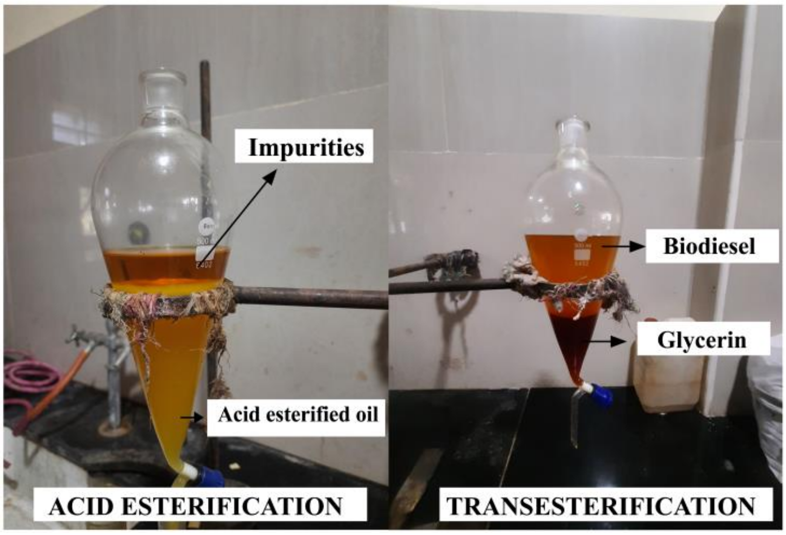

Fig. 2b. Transesterification results

2.2 Preparation of Test Fuels with Al_2O_3 and Properties Analysis

Al_2O_3 nanoparticles were procured from Intelligent Materials Pvt. Ltd., Punjab, India. The details of the Al_2O_3 were presented in Table 1. The blend CSME20 was mixed with Al_2O_3 nanoparticles at a dosing level of 50 mg/l and labelled as DHME20Al50. A magnetic stirrer was used to disperse Al_2O_3 in the CSME20 blend for 1 hour. To attain uniformity, the test fuel sample undergoes a 30-minute sonication process. The main properties of DF, DHME20, and DHME20Al50 are summarized in Table 2. The fuel properties are measured as per ASTM standards. From Table 2, it is seen that the viscosity and density of DHME20 were slightly increased with the inclusion of Al_2O_3. The inclusion of Al_2O_3 nanoparticles into DHME20 resulted in a lower flash point compared to DHME20 due to the presence of O_2 in Al_2O_3. Furthermore, the nano blended test fuel sample (DHME20Al50) was stored in a bottle under static conditions for 48 hours to check its stability, and no separation of phases was observed.

Table 1
Specifications of Al_2O_3 nanoparticles

Item	Specifications
Chemical name	Al_2O_3 nanoparticles
Purity	99.9%
CAS	1344-28-1
Average particle size	30 nm
Molecular weight	101.96 g/mol
Form / Colour	Powder/White

Table 2
The fuel properties of DF, DHME20, and DHME20Al50

Properties	ASTM Methods	DF	DHME20	DHME20Al50
Density at 30^{0}C (kg/m^3)	D4052	824	832.6	834.8
Kinematic viscosity at 40^{0}C (mm^2/s)	D445	2.37	2.62	3.10
Flash point (^{0}C)	D93	66	86	79
Calorific valve (KJ/Kg)	D5865	42,260	41,713	41,745

2.3 Nanoparticles Characterisation

The characterization of Al_2O_3 nanoparticles involved the utilization of scanning electron microscopy (SEM), and energy dispersive spectrum (EDS) techniques. The morphology and average particle size of the Al_2O_3 nanoparticles used in this study were measured by SEM. Figure 3 revealed that the shape of the nanoparticles is consistent in shape, varying in size between 20 and 40 nm, with an average particle size of 30 nm. Added to the above, it is also observed that the microstructure of nanoparticles has less defect. The EDS analysis, displayed in Figure 4 and Table 3, validated the elemental composition of the nanoparticles, identifying the presence of Al, O, and K within the Al_2O_3 composition.

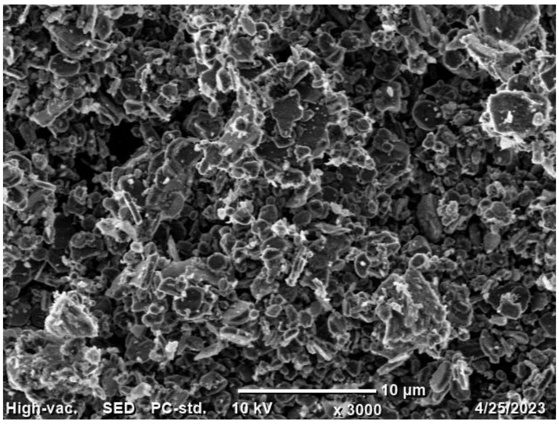

Fig. 3. SEM image of Al_2O_3

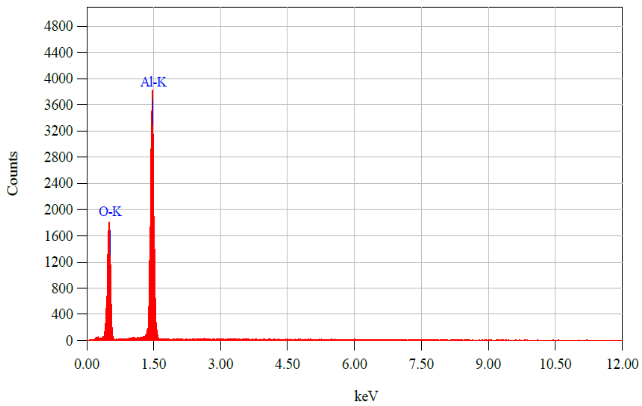

Fig. 4. EDX spectrum of Al_2O_3

Table 3
Elemental composition of the Al.$_2$O$_3$ nanoparticles

Element	Weight (%)	Atomic (%)
Al (K)	54.25	41.29
O (K)	45.75	58.71
Total	100	100

2.4 Experimental Work

Engine setup consists of a 1-cylinder, 4-stroke, and air-cooled DI-CI engine as depicted in Figure 5a. The tests were conducted at a fixed speed of 1500 rpm. Table 4 presents the technical information of the CI engine. Figure 5b shows the photographic view of the test engine. The AVL smoke meter was employed to analyze the smoke, and the AVL Di-gas analyzer was utilized to measure the pollutants from the tile pipe, such as CO, HC, and NOx. The experiments were done in two phases. Initially, the CI engine was fuelled with DF, DHME20, and DHME20Al50, and performance, engine emissions, and combustion behaviour for various loads were measured at a standard injection pressure of 210 bar for baseline data. In the second phase, the experiments were repeated for the blend DHME20Al50 at an injection pressure of 230 bar. Before recording the data, a period of 5 to 8 minutes was allotted for the engine to operate and reach a stable state.

Table 4
Technical details of the CI engine

Parameters	Engine specifications
Make	Kirloskar
Type	Research diesel engine
Cylinder diameter	87.5 mm
Stroke length	110 mm
Compression ratio	18:1
Rated power	3.5 kW
Number of cylinders	1
Speed	1500 rpm
Injection pressure	210 bar
Type of cooling	Water
Dynamometer	Eddy current
Injection timing	23^0 bTDC

Uncertainties and errors in the experimentations occur due to instruments sensitivity, human errors, and calibration. To confirm the accuracy of the recorded data, an uncertainty analysis was performed. Table 5 lists the uncertainty information of the instruments utilized in the experiments. The accuracy test of the recorded data was analyzed by error analysis using the root square technique, and it is given below. Overall uncertainty of the experiments is calculated as below:

Overall uncertainty = √ {uncertainty of [$(\text{Time})^2$ + $(\text{Load})^2$ + $(\text{Speed})^2$ + $(\text{Fuel Consumption})^2$+$(\text{Break power})^2$+ $(\text{Break thermal efficiency})^2$ + $(\text{oxides of nitrogen})^2$ + $(\text{Hydrocarbons})^2$ + $(\text{Smoke})^2$ + $(\text{Carbon monoxide})^2$ + $(\text{Cylinder pressure})^2$ + $(\text{Crank angle})^2$]}

$$=\sqrt{(0.8)^2+(0.1)^2+(0.2)^2+(0.8)^2+(0.2)^2+(1)^2+(0.8)^2+(0.9)^2+(1)^2+(0.7)^2+(0.2)^2+(0.2)^2} = \pm 2.32\%$$

Table 5
Uncertainties of different variables

Parameters	Uncertainty (%)
Time	±0.8
Load	±0.1
Speed	±0.2
Fuel Consumption	±0.8
Break power	±0.2
Break thermal efficiency	±1
Oxides of Nitrogen	±0.8
Hydrocarbons	±0.9
Smoke opacity	±1
Carbon monoxide	±0.7
Cylinder Pressure	±0.2
Crank angle	±0.2

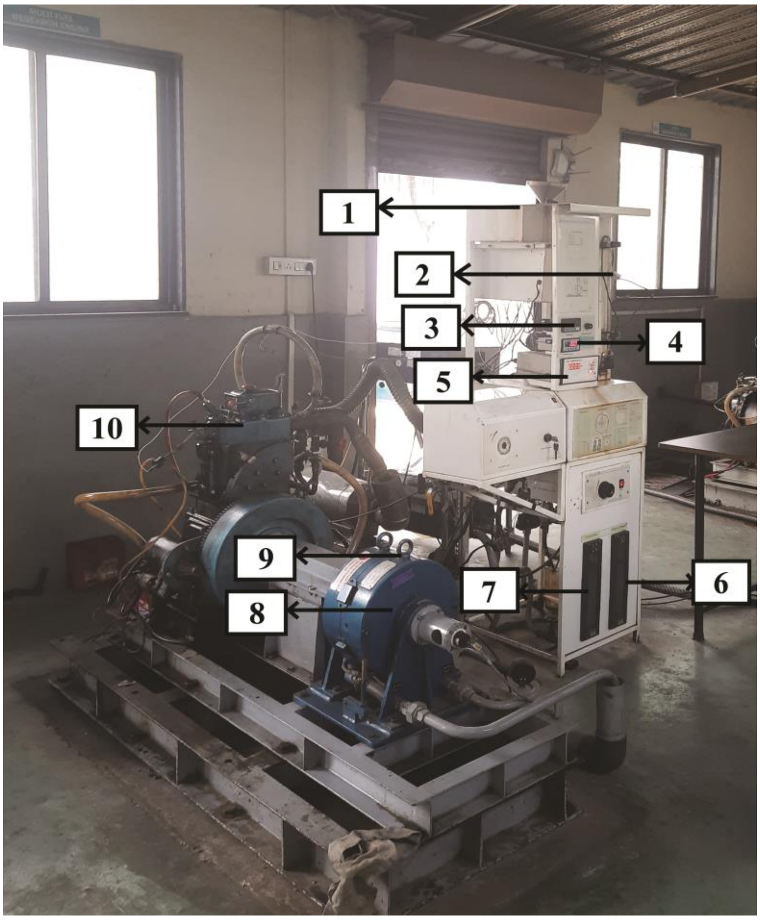

Fig. 5a. Photographic view of the test engine setup. 1. Fuel tank, 2. Fuel indicator, 3. Digital voltmeter, 4. Load indicator, 5. Speed indicator, 6. Calorimeter rotameter, 7. Engine rotameter, 8. Dynamometer, 9. Dynamometer loading unit, 10. Engine.

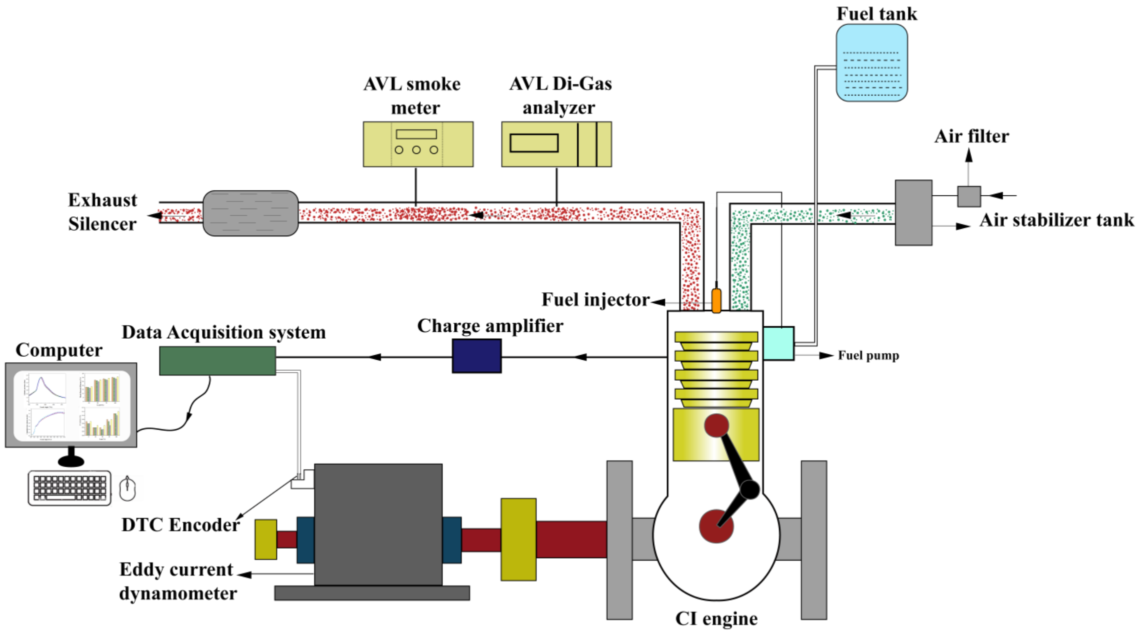

Fig. 5b. Schematic layout of the test engine setup

3. Results and discussion

3.1 Performance and Emission Characteristics

Figure 6 presents the diversity of brake thermal efficiency (BTE) with different loads and injection pressures for DHMEAl50. From the plot, it is observed that at a standard IP of 210 bar, the thermal efficiency is found to be 29.61% for DHME20 at full load, which is lesser than pure diesel (30.94%). This occurs due to the poor atomization, low volatility, and high viscosity of the DHME20. Dispersion of 50 mg/l of Al_2O_3 nanoparticles with DHME20 enhanced the thermal efficiency (32.13%) at rated load at standard IP. This is due to the proper blending of nanoparticles, which increases the ratio of surface area to volume and allows an increased amount of fuel to react with the air for complete combustion [21]. Furthermore, the IP was assessed for further enhancement of BTE. By increasing the IP from 210 to 230 bar, the BTE of the DHME20Al50 blend increased (32.45%) due to the mutual effect of blending nanoadditives and increasing IP. Increased IP accelerates the fuel droplet breaking process, enhances the spray characteristics, and paves the way for quick vaporization inside the cylinder. Hence, mixing Al_2O_3 nanoparticles with DHME20 at a higher IP decreases the delay period and enhances combustion. Kumar *et al.,* [35] observed a 2.5% higher BTE for B20 with cerium oxide nanoparticles at 240 bar IP compared to B20 operating at 180 bar IP. The results of the present work follow a similar pattern, and a maximum value of BTE is observed for DHME20 with Al_2O_3 nanoparticles at 230 bar IP.

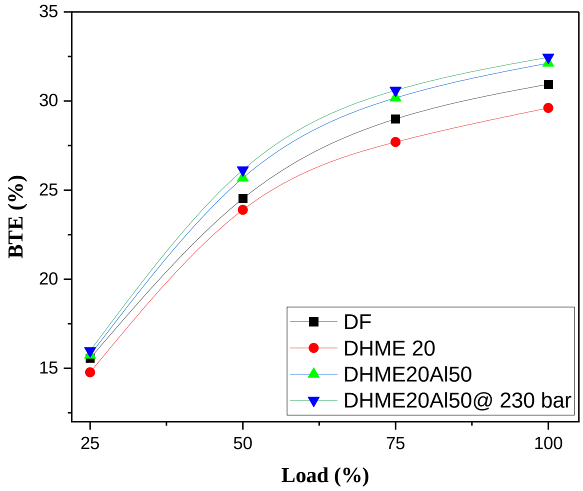

Fig. 6. BTE variation at different engine loads for test fuels

The NOx emission from the engine tile pipe for DF, DHME20, DHME20Al50 at standard IP, and DHME20Al50 at 230 bar IP at different loads is presented in Figure 7. Generally, incomplete combustion, inappropriate cylinder pressure, and O_2 content in the test fuel are the main reasons for the production of NOx. From Figure 7, the production of NOx slightly increased with the rise in load. The blend DHME20 emits lesser NOx emissions compared to DF due to its lower heating value, which led to lower cylinder pressure and temperature as well as lesser NOx emissions. At maximum load, the DHME20 with nanoparticles exhibits lower NOx by 7.59% compared to the DHME20. This is mainly due to the enhanced catalytic effect of the nanoparticles and their capacity to eliminate nitric oxide radicals [36]. The inclusion of metal oxide catalysts acts as an oxygen catalyst, resulting in enhanced combustion. It is noted from Figure 7 that the formation of NOx slightly increased by 3.42% for DHME20Al50 with an increase in IP from 210 to 230 bar. Increased IP led to improved fuel spray properties, facilitating complete combustion and rapid atomization [37].

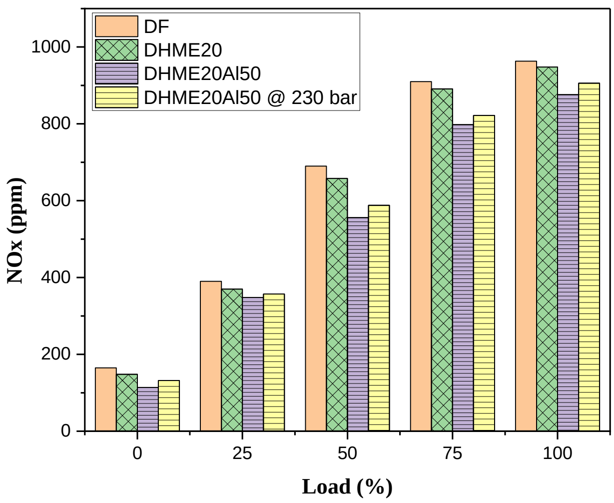

Fig. 7. NOx variation at different engine loads for test fuels

The HC emissions of all test fuels were illustrated concerning engine load as depicted in Figure 8. Incomplete combustion of the fuel is the primary factor in the production of HC emissions. The improper mixing of fuel and air is the primary cause of poor combustion. HC emission for DHME20 was observed to be lower than that of DF at 100% load, owing to the presence of O_2 in the biodiesel. By doping Al_2O_3 nanoadditives with DHME20, an 11.11% decline in HC emission was observed. The blending of Al_2O_3 nanoadditives with DHME20 increases the contact area of combustible fuel droplets with hot gases, enhancing the burning process. Furthermore, the availability of O_2 in Al_2O_3 increases the oxidation rate of hydrocarbons, promotes complete combustion, and, as a result, reduces HC emissions. An increase in IP from 210 to 230 bar enhances the capacity of fuel droplets to penetrate more deeply, thereby ensuring the mixing of fuel and air. It is seen from the plot that, for increased IP, the HC emission declined by 5.35% for DHME20Al50 on full load conditions.

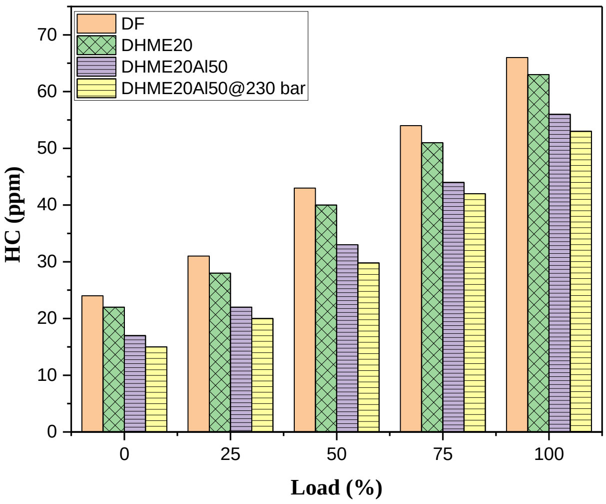

Fig. 8. HC variation at different engine loads for test fuels

The CO emissions are caused by incomplete combustion due to a lack of oxygen during combustion. The variation in the CO emission of diverse test fuels against engine loads is depicted in Figure 9. The blend DHME20 emits lower CO emissions compared to DF at 100% load due to the presence of O_2 in the biodiesel. It is seen from Figure 9 that the mixing of Al_2O_3 with DHME20 decreases CO by 11.12%. The reason for this is that oxygenated nanoparticles might cause the oxidation of carbon particles to CO_2 inside the cylinder. From the plot, it is also seen that the production of CO decreased by 7.14% for DHME20Al50 at 100% load with an increase in IP from 210 to 230 bar. This might be due to the improved air-fuel mixing, which promotes more efficient combustion of the finer fuel droplets. This is justified by comparing the current findings with the previous studies [38], higher IP with nanoparticle additives facilitates to decrease in CO.

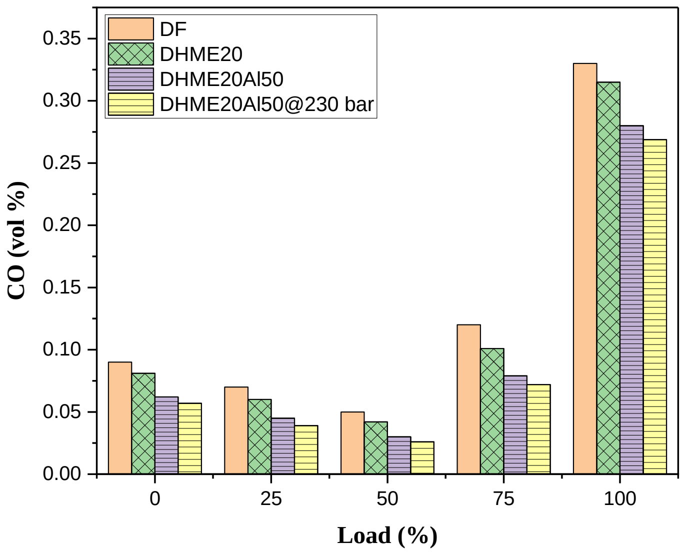

Fig. 9. CO variation at different engine loads for test fuels

Figure 10 displays the mutation of the smoke opacity of the test fuels in terms of engine load. From the plot, it is observed that the smoke opacity of all tested blends is lower at lower engine loads, but it is found to be higher at full load. The blend DHME20 exhibits less smoke than DF at maximum load due to better atomization and vaporization of blended fuel. DHME20 with Al_2O_3 nanoparticles exhibits lower smoke by 7.90% compared to DHME20. This decline, caused by a shorter ignition delay and better fuel and air mixing with Al_2O_3, leads to proper combustion of the fuel and results in less smoke. Furthermore, as depicted in the graph, the smoke declined by 3.47% when the IP was increased from 210 to 230 bar for DHMEAl50 at maximum load conditions. This reduction could be due to the formation of smaller fuel droplets resulting from the increased IP, which facilitates better dispersion and mixing. Hence, a uniform air - fuel mixture was produced, which promotes complete combustion. Kumar *et al.,*[35] observed a 14% lower smoke for B20 with cerium oxide nanoparticles at 240 bar IP compared to B20 operating at 180 bar IP. Swaminathan and Hajamaideen [38] also observed similar results from their investigation conducted by them. The results of the present work follow a similar pattern, and a minimum value of smoke is observed for DHME20 with Al_2O_3 nanoparticles at 230 bar IP.

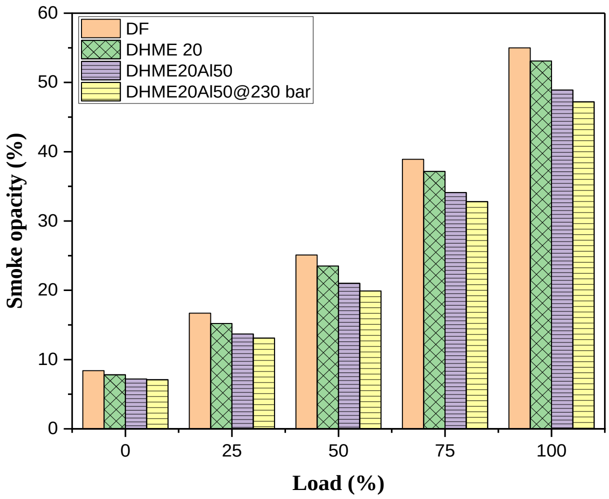

Fig. 10. Smoke opacity variation at different engine loads for test fuels

3.2 Combustion Characteristics
3.2.1 Cylinder pressure

A P-θ (Figure 11) curve illustrates the nature of cylinder pressure rise with crank angle for all tested fuels at maximum load. It is observed from the plot that, the peak cylinder pressure of DHME20 was found to be lower than pure diesel. This can be caused by the low volatility and high viscosity of DHME20. However, with the inclusion of Al_2O_3 in the DHME20, the cylinder pressure improved by about 4.99% when compared to pure DF at maximum load. Application of Al_2O_3 nanoadditives in the DHME20 may decrease the ignition delay and improve the combustion rate. Nanoadditives act as catalysts, enhancing the availability of O_2 and thereby promoting complete combustion. This leads to improved combustion [39]. By increasing the IP from 210 to 230 bar, the peak cylinder pressure of the DHME20Al50 blend increased by 0.92%. This happens because, due to a higher IP, fuel droplets are split into fine droplets, which results in uniform dispersion and complete combustion. Muthusamy *et al.,* [40] observed similar results using metal-based nanoparticles in biodiesel-diesel blend fuel.

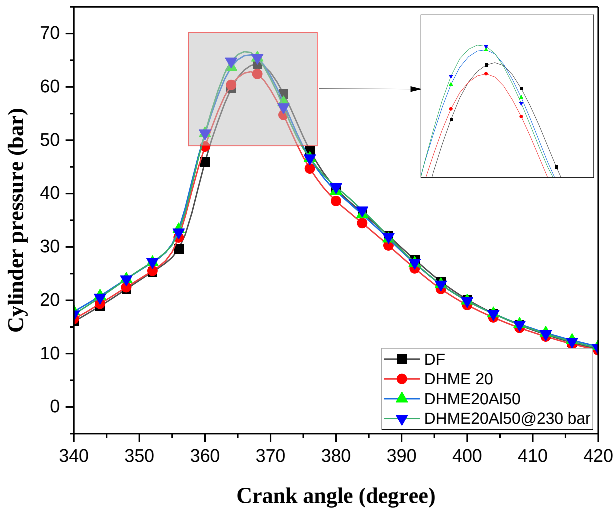

Fig. 11. Peak cylinder pressure variation at 100% loads for test fuels

3.2.2 Cumulative heat release rate (CHRR)

Figure 12 depicts the CHRR of all test fuels with different crank angles under peak load conditions. CHRR mainly depends on several parameters such as quality and type of fuel, start and end of combustion with respect to crank angle, and rate of increase in cylinder pressure[35]. It was observed that the blend DHME20 has a lower CHRR than DF due to its lower calorific value and shorter ignition delay. The inclusion of Al_2O_3 nanoparticles with DHME20 increased the CHRR by 7.25% at the rated load at standard IP. This can be due to improved heat release between the air and fuel. This enhances the rate of heat release in premixed as well as diffusion combustion process [41, 42]. It was observed that increasing the IP from 210 to 230 bar, the CHRR of the DHME20Al50 was increased by 1.89%. Increased IP leads to fine spray droplets of the test fuel, which improve the turbulence effect inside the cylinder, resulting in increased CHRR [35].

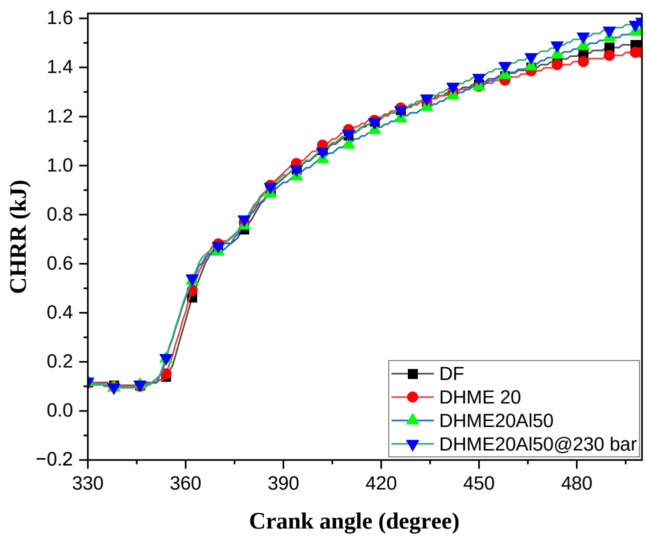

Fig. 12. CHRR variation at 100% loads for test fuels

4. Conclusion

The tests are performed to study the engine behaviour with the use of DF, DHME20, and DHME20Al50 at standard IP 210 bar. The experiments are repeated for the blend DHME20Al50 by increasing the IP from 210 bar to 230 bar. The following findings have been obtained:

i. Blending Al_2O_3 nanoadditives with DHME20 increased the BTE of the CI engine. Additionally, the higher BTE was observed for DHME20Al50 (32.45%) at IP of 230 bar, which is higher than DF (30.94%) and DHME20 (29.61%).
ii. The mutual effect of blending Al_2O_3 nanoadditives and increasing IP leads to decline in HC, Smoke, and CO emissions by compared to DF and DHME20. NOx emissions marginally increased due to fine fuel droplet distribution in the cylinder.
iii. Additions of Al_2O_3 nanoparticles to the DHME20 blend enhance the combustion characteristics of the CI engine. The presence of nanoparticles in the blend (DHME20Al50) showed a shorter ignition delay, higher peak cylinder pressure, and CHRR.
iv. Increased IP makes fuel droplets split into fine droplets, which results in uniform dispersion and complete combustion for DHME20Al50. Also, peak cylinder pressure increased to 66.59 bar, which is higher than DF and DHME20.

This study concluded that mixing Al2O3 with DHME20 might be a better alternate fuel for a CI engine operating at 230 bar of IP.

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