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An impact of emulsified cottonseed biodiesel with Nano additives on low heat rejection engine

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Abstract
This paper reports the role and impact of nanoparticles contingent on emulsified cottonseed biodiesel. The Nano-emulsified biodiesel was made with Aluminum oxide (Al_2O_3) and Titanium dioxide (TiO_2). The amalgamation of 90% blend 20 (B20) with 10% water has been considered as the base of Nano-emulsified biodiesel called B20W10. Here, four different combinations, such as 100 ppm of Al_2O_3 and TiO_2 and 200 ppm of Al_2O_3 and TiO_2 are used for the preparation of cotton seed Nano emulsified biodiesel fuel samples. The current diesel engine parts such as cylinder liner, piston top, and inlet, exhaust valve have been coated with fly ash material with a thickness of 200 µm to convert conventional engine into a low heat rejection (LHR) engine. Furthermore, an experimental investigation was carried out on the LHR diesel engine with neat diesel and prepared fuel samples at various loads. From that investigation noticed the maximum Brake Thermal Efficiency (BTE) for B20W10Al200 at maximum load, is around 13.79% higher than the neat diesel operation. And also observed the drastic reduction of HC, CO, and NO_X and emissions for B20W10Al200 it is 55.35%, 33.03%, and 16.06% lower than the diesel operation at maximum load. Surprisingly, it has been noticed that the interaction of Nanoparticles with Nano-emulsified biodiesel has a quite prominent impact on the fuel in the LHR engine.

Keywords LHR engine · Biodiesel · Nanoparticles · Aluminum oxide · Titanium dioxide

1 Introduction

There is an enormous use of diesel engines in automobile vehicles because of their greater resilience and effectiveness. The world of diesel has proven to be one of the major contributors to the economic growth of modern civilization even though it leads to air pollution (Taymaz, 2006). The number of vehicles in the state of Delhi was noted to be 2.71 lakh and 44 lakhs in the year 1971 and 2004, respectively (Senthil Kumar et al., 2009). These numbers indicate demand and use of vehicles that are increasing day by day. Specifically, in India, the consumption of diesel is five times higher than petrol. According to reports of

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the Indian government on pollution, Delhi is a major victim of air pollution. Worldwide, nearly 30% of air pollution is due to automobile vehicles which in turn increases global warming (Geng et al., 2015). National Aeronautics and Space Administration (NASA) scientists have released a press note on 12 November 2015, which states that the rise in carbon dioxide (CO_2) level is beyond the safe limit. At present, carbon dioxide (CO_2) emission from IC engines is 50% and the rest of the percentage is covered by industrial emission. On the other hand, the number of plants or trees on earth is decreasing and the currently available plants are unable to soak up carbon dioxide (CO_2) from the atmosphere (Roy et al., 2014). On a global platform, concerns about air pollution have become an imperative subject of matter. This grave situation has given rise to the need for alternative fuel. India fulfills its need for fossil fuel by importing from other countries by taking these facts into account, the Indian government is encouraging the use of alternative fuels although fossil fuels are still in use (Gopidesi & Rajaram, 2019).

In the race for alternative fuel, biodiesel is getting more recognition and importance due to its high performance and properties similar to diesel. To get more benefits and to make it economically viable, now a day's researchers are bringing water into play (Sadhik Basha & Anand, 2011). There is adequate proof available related to satisfactory results from biodiesel-water emulsified fuel (Patel & Sankhavara, 2015). Primarily there are three ways to introduce water in combustion chambers that are listed below.

- Produce emulsion of biodiesel-water with help of appropriate surfactant
- Offer water in the combustion chamber in form of a shoot with help of a separate injector.
- Fumigation is an integration of water with available induced air in a combustion chamber

As per previous literatures, it is found that from all the above options; emulsion is quite effective. The quality of micro-explosion reactions makes emulsified fuel different and unique from others. In the year 1965, for the first time, the micro-explosion term was used (D. Sai K, R. K. Gopidesi, P. Sr & Nagarjuna, 2018). A diesel engine is an appropriate choice for the utilization of emulsified fuel rather than a petrol engine because of its high compression ratio along with high temperature and pressure (Domakonda & Puli, 2012). Micro-explosion is the phenomenon where one or two different liquids get evaporated at different working temperatures. There is an appropriate sequence of volatility in the process of micro-explosion reaction (Kojima et al., 2014). Following this, a less volatile liquid droplet provides a coating on high volatile liquid droplets. Eventually at high temperature; the first coat that is less volatile liquid gets evaporated, after which a highly volatile liquid droplet gets evaporated which makes this fuel economically viable. On the other side, a water-biodiesel emulsion is a reason for ignition delay which helps to increase heat discharge rate, increment in peak pressure, and irregularity in engine operation (Gopidesi & Premkartikkumar, 2019). Some researchers claim that the difficulty in ignition delay can be solved by adding nanoparticles into it. Nanoparticles are material elements that are in nanometer size. Moreover, nanoparticles have more surface area to volume ratio. The major feature of nanoparticles is their size due to which there is no probability of filter blocking and injector nozzle blocking. Some researchers have noted that doping some quantity of Nano additives like alumina, titanium, and ceria in biodiesel and emulsified fuel enhances the bonding between water and diesel or the biodiesel blend (Gopidesi & Premkartikkumar, 2018). Until now, some of the researchers attempted trials to utilize nano-emulsified fuel with different nanoparticles. Venu et al. (Yang et al., 2013) presented an experimental investigation on biodiesel-ethanol blends emulsion along with TiO_2 (Titanium dioxide) nanoparticle, ZrO_2 (Zirconium oxide) nanoparticle, and DEE (Diethyl ether) as additives. It observed that each additive has a different impact on engine performance such as titanium dioxide produced lower BSFC and CO emission whereas an increment in NO_x was noted. On the contrary, zirconium oxide is given more BSFC and CO even though an increment in HC is also observed. In the case of diethyl ether, increment in HC and CO was observed whereas NOx, BSFC, and smoke reduction were shown in the result. Jeryrajkumar et al. (Tarlet et al., 2009) investigated two different types of nanoparticles such as cobalt oxide (CO_3O_4) and titanium dioxide (TiO_2) mixed with *Calophyllum inophyllum* biodiesel (B100). The size of nanoparticles is considered as 100 nm. They found an incredible improvement in the engine performance along with a reduction in emission of particulate matter (PM), carbon monoxide (CO) but a minimum increment was also observed in the case of NO_x. Basha and Anand (2012) considered alumina nanoparticles in experimentation along with water-diesel emulsion. Experimentation was carried out on a single-cylinder diesel engine. It observed that the performance of nano-emulsified water-diesel fuel was more effective compared to water-diesel emulsion fuel. Aalam et al. (Leong et al., 2017) used aluminum oxide nanoparticles along with 25 percent of *Ziziphus jujuba* methyl ester blended fuel for experimentation work. The concentration of nanoparticles considered for this emulsion is 25 ppm and 50 ppm. It is noted that aluminum oxide at 50 ppm concentration is more effective than 25 ppm concentration even though as per result increment in BSFC and heat release rate observed.

As per previous literature, it is observed that increment in heat release rate is a common problem not only in nanoemulsion but also in neat diesel-operated engines. After successful combustion of fuel in the engine, around one-third of the energy gets converted to useful mechanical energy which is useful and the remaining amount of energy will be wasted (Annamalai, et al., 2016). It noted that about 30% of heat energy from the engine is discarded to coolant; in the year 1970, for the first time, Thermal Barrier Coating (TBC) introduced by Kvernes dealt with this heat release problem in diesel engines (Venu & Madhavan, 2016). TBC is nothing but a layer of insulation of material components that resist heat loss during working operation. The engine that is insulated by TBC material to enhance efficiency and to reduce heat rejection from the combustion chamber is called the Low Heat Rejection engine (LHR) (Jeryrajkumar et al., 2016). These are the following aspects that make LHR engines more useful than traditional diesel engines (Basha & Anand, 2012).

i. Required time for ignition of fuel is quite less
ii. Effective combustion period increases
iii. Proper utilization of fuel is possible
iv. Decreased rate of heat release

From all the above discussion, it is observed that an enormous amount of research work has been done on Nano-emulsified diesel fuel and LHR engines separately. By considering these aspects, the objective of this manuscript is to present an experimental investigation of Nano-emulsified cottonseed biodiesel along with nanoparticles such as Al_2O_3 and TiO_2 fuelled in fly ash-coated LHR engine.

2 Materials and methods

In this manuscript, an experimental investigation was conducted in three stages. The first stage is all about the preparation of nano emulsified biodiesel fuel with different nanoparticles concentration. In the second stage, modification of the engine is carried out. Such as conversation of the non-coated engine into the coated engine with help of fly ash as applying coating material on engine components. In the third stage, considerable performance and emission tests for Nano-emulsified biodiesel and neat diesel were carried out on a single-cylinder four-stroke diesel engine with coated conditions. A detailed description of the procedure for the preparation of Nano-emulsified biodiesel fuel and LHR engine preparation has been presented below.

2.1 Preparation of nano-emulsified fuel

For the preparation of Nano-emulsified fuel, cottonseed biodiesel is adopted which is prepared from refined cottonseed oil through the transesterification process by using Sodium hydroxide (NaOH) as a catalyst. An experimental layout for Nano-emulsified biodiesel preparation is shown in Fig. 1. A blend20 (B20) is used as biodiesel which is prepared by combining 20% of Methyl ester with 80% of diesel. The Nano-emulsified testing fuel is formed by mixing 10% of water with 88% of cottonseed biodiesel (B20W10).

Were.

1. Source of power
2. Auto power Convertor
3. Stand
4. Motor
5. Case of gear
6. Fuel vessel
7. Stirrer

Throughout the stirring process, surfactants such as 1% of Span 80 and 1% of Tween 80 were mixed dropwise into the biodiesel water emulsion. The stirring process is kept for

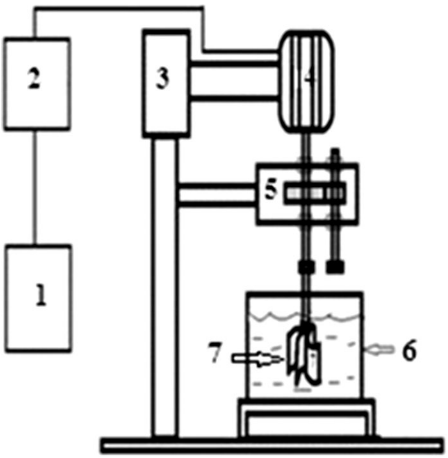

Fig. 1 An experimental layout for Nano-emulsified biodiesel preparation (Vellaiyan et al., 2018)

a duration of 40 min. As per the previous works, if the water quantity is more than 10% in diesel fuel, it causes an extended ignition delay time in addition to the uneven engine process, hence 10% of water quantity along with biodiesel was preferred (Vellaiyan et al., 2018). In this work, the ultrasonication method was adopted to integrate the nanoparticles such as Al2O3 and TiO2 in different concentrations for emulsification of fuels. Figure 2 illustrates the flow chart for the preparation of different fuel samples.

Different testing fuel samples were prepared by varying concentrations of mass fraction along with 10% water named B20W10. By keeping that in consideration magnitude for nanoparticles was 100 ppm for Al_2O_3, TiO_2, and 200 ppm for Al_2O_3, TiO_2. Total four test fuel samples were prepared named B20W10Al100, B20W10Ti100, and B20W10Al200, B20W10Ti200 with help of an R-4C ultrasonicator. To get perfect emulsification ultrasonicator operated under a frequency of 50–60 kHz for 40 min. By considering this fact in the present investigation prepared emulsified fuel kept in a transparent bottle for 7 days to check stability status. The colors of prepared nano-emulsified fuel samples were turned to milky white. The emulsified nano bio fuel showed lower calorific value than the diesel fuel due to the addition of non-calorific value fluid water. The Calorific value of emulsified nano bio fuel was noted as 38,300 kj/kg and also it contain higher viscosity than the pure diesel (3.5 cST at 40 °C) it is about 5.43 cST at 40 °C. Figure 3 represents all four fuel samples that were prepared by an ultrasonicator.

2.2 LHR engine preparation

Required fly ash for engine component coating was collected from Damodaram Sanjeevaiah thermal power plant located at Nelaturu Village, Andhra Pradesh, India. To maintain the uniformity in the size of fly ash at 65–75 µm while coating, initially the acquired fly ash powder was screened using sieves of the respective sizes. The reason behind the selection of fly ash coating material is that fly ash is west material from industries. Although, the availability of fly ash is enormous. Even though some researchers have proven that fly ash is possible and effective TBC material. Figure 4 illustrates a scanning electron microscope (SEM) morphology image where the fly ash particle was observed in a spherical

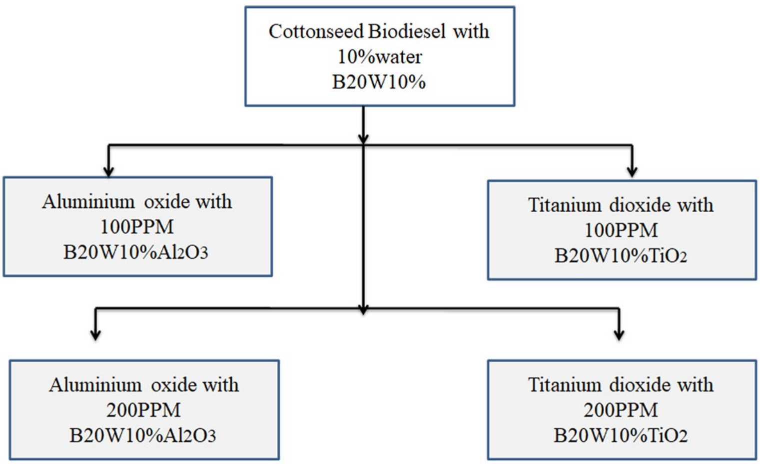

Fig. 2 Flow chart for preparation of different fuel samples

Fig.3 Sample representation of nano-emulsified Cotton seed biodiesel with different concentration

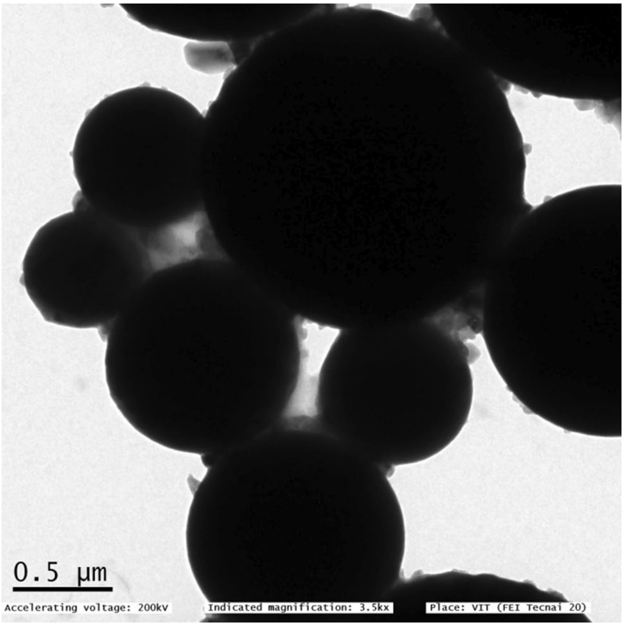

Fig. 4 Scanning electron microscope (SEM) micrograph of fly ash

shape. Furthermore, composition analysis for fly ash was carried out through SEM detailing of each composition mentioned in Table 1.

For the experimentation purpose, different engine components such as exhaust and inlet valve, piston crown, cylinder liner were considered for fly ash coating. The plasma spray

Table 1 List of element analysis for fly ash

Element	Weight%	Atomic %
C K	3.18	7.69
O K	25.36	46.05
Mg K	1.92	2.29
Al K	6.13	6.60
Si K	4.15	4.29
Ca K	9.17	6.65
Cr L	18.23	10.19
Fe L	18.45	9.60
Ni L	13.41	6.63

coating technique was adopted for coating purposes due to its rapid deposition ability and lower cost in comparison with other spray coating techniques. Perhaps Kirloskar AV 1 single-cylinder diesel engine is taken into consideration for a coating process. Figure 5 shows an experimentation workstation or setup where the performance of testing fuel got tested. The coating operation was done by setting the process parameters such as power, current, and voltage at 20 kW, 500 A, and 65 V, respectively.

At initial stage instead of applying fly ash powder directly on engine components it was applied on working specimen with two different thickness 100 µm and 200 µm to carry out wear test. The purpose to carry out wear test is to understand peeling tolerance

Fig. 5 An experimental setup for fuel testing

or wear behavior of fly ash powder under testing circumstances. Specifically, for wear test, two different substrate specimens taken in to consideration with the dimension of 20 mm × 30 mm × 10 mm. To conduct comparative analysis two different substrate specimens prepared for this test, by applying fly ash coating with a thickness of 100 µm and 200 µm. Generally, engine components such as cylinder liner, piston ring has to work under surpass temperature that is 540 °C. By considering this temperature, the response of the coating surface with different traction force at specific 540 °C temperature has studied in this testing. There is a conductive metal coil inside the furnace which leads to supply required heat in the working chamber. For the purpose of wear test a real time pointer on specimen machine Scratch tester (TR 104) utilized for load up to 3 N for distance of 9 mm. Figure 6 shows a graphical result of the wear test.

The total length of stroke was 9 mm for testing. It found that at 2.5 mm stroke length, 2.7 N force for 100 µm thickness coating and 3.0 N traction force for 200 µm, respectively Whereas at 9 mm stroke length 2.0 N force for 100 µm thickness coating and 2.4 N traction force for 200 µm, respectively. However, it found that 200 µm is quite strong than 100 µm. On this basis of experimentation 200 µm thickness of fly ash coating has taken into consideration for engine components for further experimentation.

Before coating operation, the sandblast process was carried out to get surface roughness (Ra) of 4–5 µm for selected components. After sandblasting operation cleaning of the selected component is done by high pressurized dried air. Instead of applying a 200 µm fly ash coating layer directly on the substrate, a coating layer of 100 µm was applied twice on the substrate to get a uniform and effective coating. Correspondingly, at the second stage, the first layer of coating with 100 µm thickness was prepared by fly ash powder injection at a flow rate of 10 g/min using argon gas with a flow rate of l/min into the plasma spray flame. The purpose of plasma spray flame is to provide high velocity along with high heat and acceleration for the coating material. This results in heating of the substrate surface which gets cooled immediately forming a coating on it. Likewise, the second layer of fly ash with a thickness of 100 µm was applied to the first coating layer. The result of this two-step process is an effectively coated engine component with fly ash of 200 µm thickness.

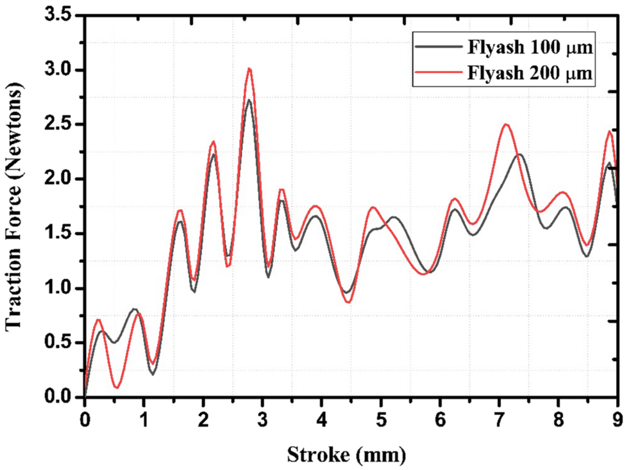

Fig. 6 Traction force (Newton) versus stroke (mm) of the fly ash-coated specimen

2.3 Error and uncertainty analysis

The accuracy of the experimental results is predicted by estimating the percentage of errors. Errors are common in experiments due to the calibration of instruments, surroundings, and observations. Error assessments of the experimental data are calculated using systematic equations. The uncertainty analysis comprises the mean of repeat measurements to estimate the true value. The average of six readings of a specific parameter was considered for the error analysis. The error bars are represented in all the engine characteristics to indicate the uncertainty in the reported measurement. The percentage uncertainties of the calculated and measured parameters are demonstrated in Table 2.

The assurance of a few unidentified uncertainties settled boundaries is finished through a general numerical articulation. The precision of these outcomes is assessed by the square root method proposed by Holman (2000).

$$\frac{U_y}{y} = \left[\sum_{i=1}^{n}\left(\frac{1}{y}\frac{\partial y}{\partial xi}U_{xi}\right)^2\right]^{1/2} \tag{1}$$

The uncertainty for the.

The percentages of the uncertainty of different measured parameters are evaluated and the overall uncertainties of the investigation are expressed as follows.

$$\begin{aligned} &= \sqrt{[(BTE)^2 + (BSFC)^2 + (CP)^2 + (HRR)^2 + (HC)^2 + (CO)^2 + (NO_X)^2]} \\ &= \sqrt{[(0.8)^2 + (0.9)^2 + (0.2)^2 + (0.5)^2 + (0.8)^2 + (0.07)^2 + (0.7)^2]} \\ &= \pm 1.76\%. \end{aligned} \tag{2}$$

The uncertainty estimations of every gear were assessed. The general uncertainty of the current test was determined as ± 1.76% and it is greatly lower than the ± 5%. Notably, the satisfactory range for the uncertainty is lower than the previously mentioned esteem. In this manner, the general uncertainty of the framework was inside satisfactory cut-off points.

Table 2 Accuracies and the uncertainties of the measured parameters

Device specifications	Range	Accuracy	Percentage uncertainties
AVL Smoke meter	0–100	± 0.1	± 0.5
Crank angle Encoder	0–720˚CA	± 0.2˚CA BTDC	± 0.4
Pressure Transducer (bar)	0–100 bar	± 0.1 bar	± 0.2
CO emission	0–10 vol.%	± 0.01 vol %	± 0.07
NO_X emission	0–4800 ppm	± 10 ppm	± 0.7
HC emission	0–30,000 ppm	± 15 ppm	± 0.8

3 Result and discussion

The objective of the experimentation carried out in this manuscript is to examine and explore the consequences of all four Nano-emulsified test fuels on a coated diesel engine. While testing Nano-emulsified fuel in coated engine 1500 rpm was considered through the process along with diverse load between 0 and 100%. In addition to this various samples of nano-emulsified test fuel are compared with diesel and biodiesel blend 20 along with 10% water into it (B20W10) as a baseline. The whole result of the experimentation for engine test is divided into three aspects namely performance, emission, and combustion that are explained in detail in the section below.

3.1 Engine performance aspect

Engine performance factor has separate importance in case of engine testing process. Perhaps underperformance aspect, several proportions such as brake thermal efficiency, brake specific fuel consumption is decoded subsequently in this segment.

3.1.1 Brake thermal efficiency

Diversity in the magnitude of brake thermal efficiency (BTE) for test fuel such as diesel, emulsified biodiesel (B20W10), nano-emulsified fuel with Al_2O_3 and TiO_2 at dosage levels 100 and 200 ppm is illustrated in Fig. 7. From the Figure, it is apparent that a raise in load gives rise to a raise in BTE. The primary reason behind the upgrading in BTE as per load condition is due to the accomplishment of brake power advancement along with the test fuel supply rate. As per an experimentation result graphs it found that maximum BTE is 32.59% for B20W10Al200, 31.99% for B20W10Ti200, 31.79% for B20W10Al100, 29.99% for B20W10Ti100, 29.1% for B20W10, 28.64% for diesel at maximum load

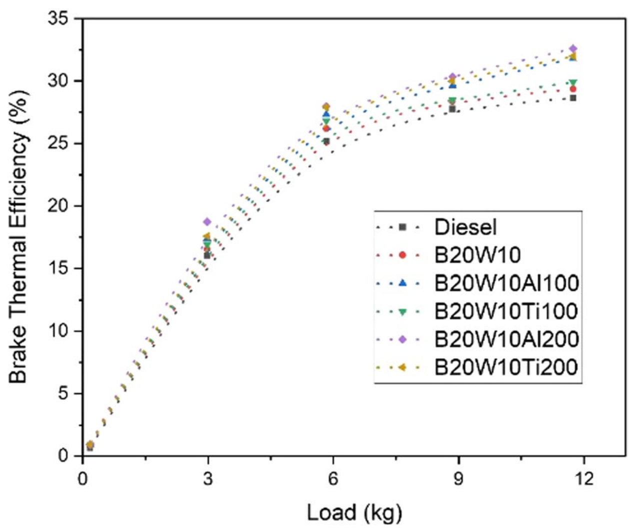

Fig. 7 Diversity in the magnitude of brake thermal efficiency (BTE) for test fuel

condition. Al_2O_3 is quite efficient when compared to TiO_2. BTE of B20W10Al200 was 13.69% higher than the pure diesel operation. The possible reasons behind this incredible result are the micro explosion reaction of water in biodiesel as well as the catalytic upshot of aluminum metal oxides. Whereas, this reaction bust up combustion phenomenon that leads to show progress in BTE. Syed Aalam (Aalam et al., 2015) also recorded the same nature and behavior as a form of result from aluminum oxide nanoparticles. However, existing water droplets in nano-emulsified fuel tends to evaporate quickly and effectively mixing of fuel atoms with air. Supplementary, the presence of nanoparticles in fuel serves a significant surface-to-volume ratio that helps to speedy evaporation and effective atomization. On top of that offered nanoparticles in emulsion key reactor to fragment hydrogen atom from water and that can participate in combustion phenomenon directly.

3.1.2 Brake specific fuel consumption

Numerous magnitudes predominantly in Brake specific fuel consumption (BSFC) regarding diesel, B20W10 along with nano-emulsified test fuel is illustrated in form of the graph as Fig. 8. Fundamentally, BSFC is an indication or ability of any engine that translates provided energy to convenient work output. Perhaps inferior value for BSFC is quite looked for. The association of the calorific value of fuel and BSFC for that particular fuel is inversely prepositional to each other. Based on the work carried out, it is clear that BSFC for diesel and B20W10 is quite high than the rest of the test fuels. The possible reason behind more development in BSFC is subordinate heat gratified of diesel compared to B20W10Al200. Sobhani M et.al (Sobhani et al., 2014a) also studied the same material as fuel additives for their work. They found that grain of aluminum oxide cracked or micro explosion phenomenon that enhanced combustion process as well. This subordinate heat gratified cause to accelerate fuel consumption. It is observed that all four nano-emulsified test fuels B20W10Al100, B20W10Al200, B20W10Ti100, B20W10Ti200 have lower BSFC than diesel fuel. The fall in fuel consumption is triggered as a consequence of

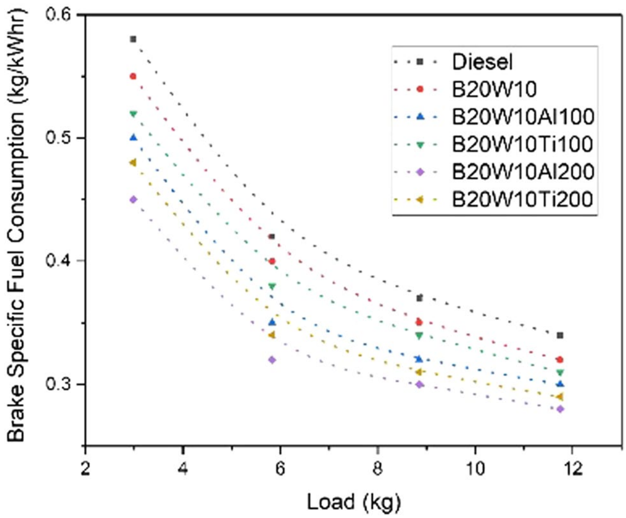

Fig. 8 Numerous magnitudes predominantly in Brake specific fuel consumption for tested fuel samples

micro explosion response in addition to the subordinate atomization of water in the case of nanoemulsions throughout nanoparticles as a major part of testing fuel. Accessible water in case of nano-emulsified fuel that major cause to drop-down fuel droplet size addition to that enhances evaporation rate as well. However; attendance of nanoparticles such as Aluminum oxide and Titanium dioxide in test fuel samples correspondingly quickens evaporation rate as well. The effect of this helps to reduce hydrocarbons along with inferior energy consumption.

It recorded that BSFC for diesel is 0.3 kg/kWh for B20W10Al100 is 0.31 kg/kWh for B20W10Al200 is 0.28 kg/kWh at full load condition. The lower specific fuel consumption was recorded at max load for all the samples and drastic reduction was noted for B20W10Al200.

3.2 Engine emission aspect

Apart from the engine performance aspect emission is an important aspect as per engine experimentation concern. This aspect is not only limited as part of engine results and discussion but also has a significant impact on the environment as well. However, this section of the manuscript emphasizes engine emissions such as Hydrocarbon Emission, No_x Emission, Carbon monoxide Emission, and Smoke as well.

3.2.1 NO_x emission

Fundamentally, NO_x emission is a by-product derived due to high temperature in the combustion chamber during the combustion process. In Fig. 9 different levels of NO_x emission particularly for tested fuel is visible. However, all nano-emulsified tested fuels have lower NO_x emissions when the result is concerned. Upgrading in certain number accomplished as an effect of nanoparticles as a reactor. Also, water atoms react as heat absorbers as a part of the micro explosion. Altogether this factor works as a major

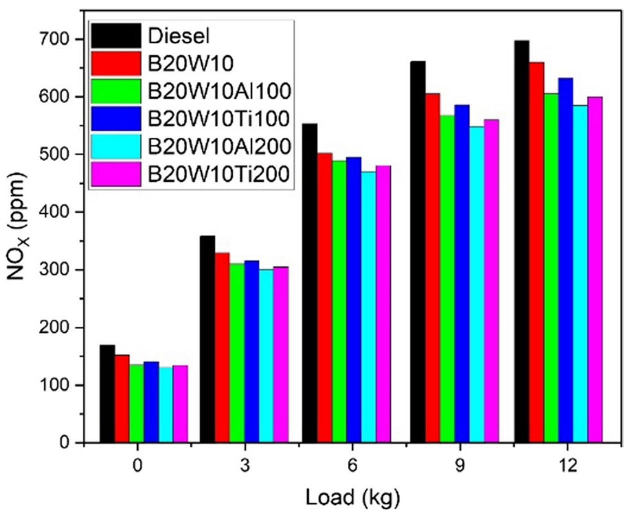

Fig. 9 Different levels of No_x emission particularly for tested fuel

player in NO_x emission reduction particularly in nano-emulsified tested fuel. As per the obtained result, it is clear that NO_x emission in the case of diesel is 697 ppm that is quite more than the rest of the tested fuel. Lower NO_x emission that is around 585 ppm found in case of B20W10Al200 at full load operating engine condition. Generally, throughout the combustion phenomenon free radicals is a key factor to find higher NO_x emission as engine emission outcome. Aalam C et.al (Aalam et al., 2015) has noticed quite the same effect on NO_x emission. However, the author found nanoparticles have a positive effect as an overall result. Whereas in this case, nanoparticles act as a breakthrough for free radicals that helps to maintain NO_x emission under control.

3.2.2 Hydrocarbon emission (HC)

Figure 10 represents magnitude variation in hydrocarbon emission for all tested fuel samples. Cause of lean fuel mixture along with inadequate fuel evaporation along with lower cylinder temperature, hydrocarbon emission is a by-product of these circumstances. Primarily at initial load condition, higher HC emission is evident for all tested fuel samples. Whereas at peak load condition drop in HC emission got noticed for all fuel samples. However, diesel fuel is observed to have lower HC emission than B20W10 due to an efficient fuel combustion response from diesel at high load conditions (Kumar, 2015). In addition to this B20W10Al200 has recorded lower HC emission out of all nano-emulsified fuel. It is around 55.35% lower than diesel operation. Perhaps the presence of Al_2O_3 200 ppm works as an oxygen cushion on top of that it supplies significant oxygen throughout the combustion phenomenon that leads to reduced HC as an inclusive effect.

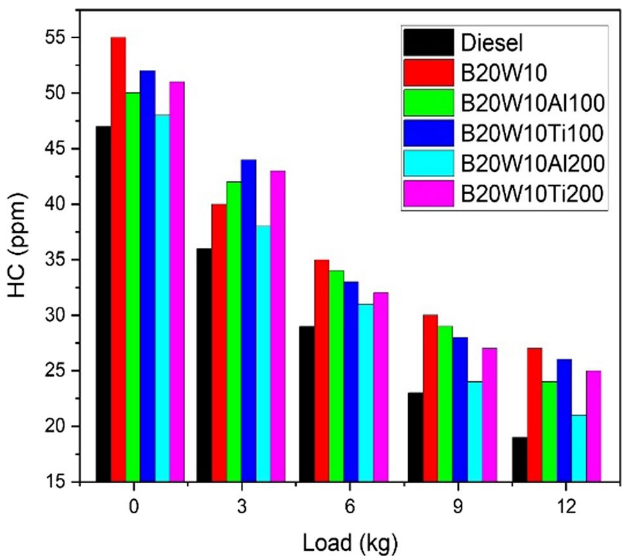

Fig. 10 Represents magnitude variation in hydrocarbon emission

3.2.3 Smoke emission

Engine load condition is a major key factor that decides the amount of fuel supply to the combustion chamber while the engine is under testing or running condition. Whereas Fig. 11 represents at more load condition more fuel supplies along with significant smoke increment. As far as smoke magnitude is concerned, diesel has recorded lower smoke than Emulsified test fuels. This result indicates that diesel has better combustion experiences than B20W10. Whereas in the case of nano-emulsified fuel smoke emission for B20W10Al200 has recorded significantly lesser smoke. Even though as per literature survey it cleared that efficient quantity of nanoparticles in fuel work as chemical buster while combustion phenomenon (Dhana Raju et al., 2018; Mujtaba et al., 2021). On the other hand, the remaining nano-emulsified fuels recorded more smoke. That could be caused by combustion grouping features such as less oxygen throughout the process. That leads to upsurges C–C bond and development of free radicals that lead to oxidation of shoot particles.

3.2.4 Carbon monoxide emission

Several magnitude levels in carbon monoxide (CO) emission for all tested fuels are represented in Fig. 12. It is a known fact that biodiesel has a significant amount of oxygen that helps to keep CO emissions at a lower level even in emulsified and nano-emulsified fuel than diesel fuel. Fundamentally, the causes for HC emission and CO emission have similarities in nature (Soudagar, 2021; Venu Raju et al., 2019). Subsequently, B20W10 has biodiesel into it so naturally, it has a sufficient amount of oxygen that helps to retain CO emission at low level than diesel for that matter. However, interference of nanoparticles such aluminum oxide100 ppm, 200 ppm and titanium dioxide 100 ppm, 200 ppm in emulsified fuel that expressed lesser CO emission. Out of all nano-emulsified tested fuel B20W10Al200 has recorded significantly lesser CO emission. It is about 33.03% lower

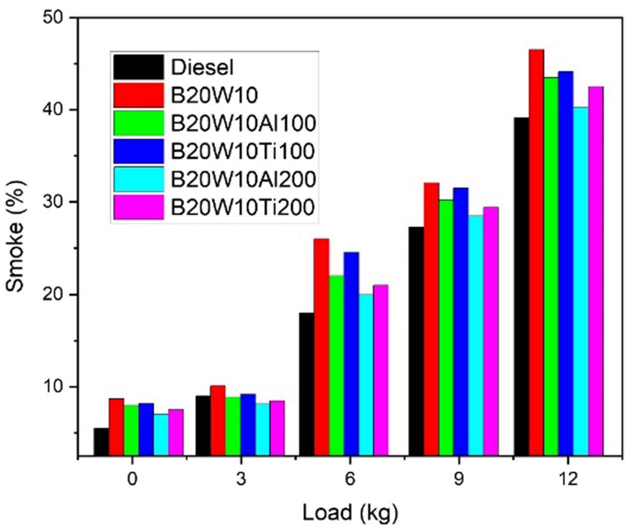

Fig. 11 Variation in smoke emission

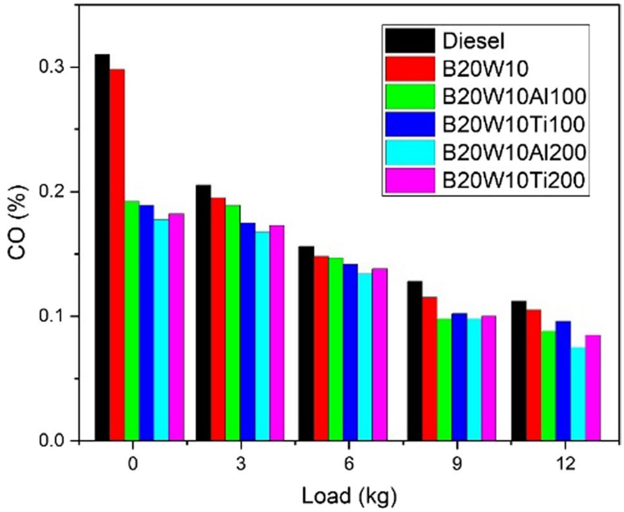

Fig. 12 Several magnitude levels in carbon monoxide (CO) emission for all tested fuel

than the diesel operation. Moreover, incredibly available oxygen has a major role to play as supplementary that leads to effective combustion and lesser CO emission altogether.

3.3 Engine combustion aspect

Fundamentally, the role of nanoparticles as fuel additives is noticed in the fuel combustion phenomenon. Along with that, this is the phase where nanoparticles activate strongly and represents a take on the fuel combustion process. By considering in account this combustion factor is explained and elaborated in this section such as net heat release rate, Cylinder Pressure.

3.3.1 Net heat release rate

Figure 13 shows the net heat release rate for all tested fuel along with crank angle in form of a graph. As per graphical representation, it was noticed that the form of the arch for all tested fuels is quite similar. Although it detected that fuel consumption is started in emulsified test fuel samples than that diesel fuel. However, a lesser heat release rate is get noticed in the case of the B20W10 fuel sample than the rest of the fuel samples (Dhana Raju et al., 2019). Attendance of water atoms in nano-emulsified fuel upsurges fuel gathering more fuel causes due to developed ignition delay period that advances net heat release rate as well. A mathematical Equation is developed by Heywood for the evaluation of the total heat release rate during combustion in sync with the First Law of Thermodynamics.

$$\frac{dQ}{d\theta} = \left(\frac{\gamma}{\gamma} - 1\right)P\left(\frac{dV}{d\theta}\right) + \left(\frac{1}{\gamma} - 1\right)V(\mathrm{dP}/\mathrm{d}\theta) \quad (3)$$

where is the heat release rate in J/θ, P indicates the pressure inside the cylinder in Pascal, denotes the adiabatic index, *V* represents the volume of combustion space in m^3.

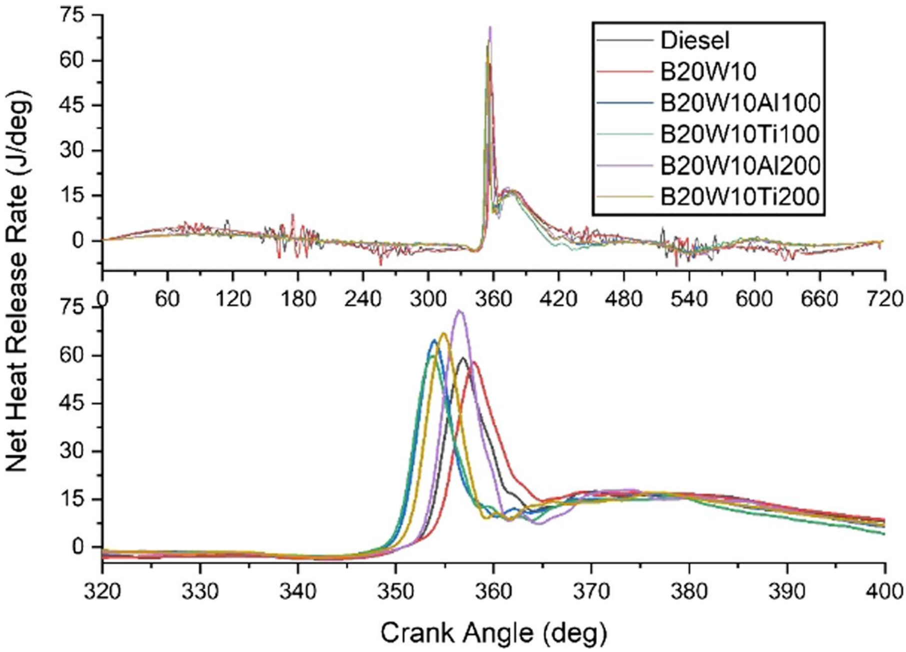

Fig. 13 Net heat release rate for all tested fuel along with the crank angle

The heat release rate is the amount of heat energy liberated with the combustion of fuel inside the combustion chamber.

3.3.2 Cylinder pressure

While studying the combustion aspect of any engine an important step is to analyze cylinder pressure. The primary reason behind that is by the basis of the first law of thermodynamics cylinder pressure is the key factor or parameter (Venu et al., 2020; Venu, Subramani, et al., 2019). That indicates the progression of translation of heat energy into mechanical work. Furthermore, cylinder pressure data can be excellently used for heat release rate and cumulative heat release rate calculations as well. Figure 14 illustrates variations in-cylinder pressure for all testing fuels along with crank angle. Most of the time it is anticipated that as load upsurges at the same time fuel consumption also get increases to balance power outcome.

Remarkably, as per experimentation result graphs it observed that obtained cylinder pressure along with crank shown pile up angle throughout engine testing process. Although it was noticed that B20W10Al200 has more cylinder pressure as compared to the rest of the test fuel (Gan & Qiao, 2011; Patil, 2017). However, the probable reason behind this drift is the effective combustion of B20W10Al200 than the remaining test fuel samples. As matter-of-fact enrichment in-cylinder pressure, 65 bar has noted down for B20W10Al200, 64 bar for B20W10Ti200, and 55 bar for B20W10Al100 at full load condition. An overall, it was noticed that due to participation of nanoparticles in emulsified fuel is quite effective (Prakash et al., 2015; Ramesh et al., 2018). The basic reason behind this effect is the

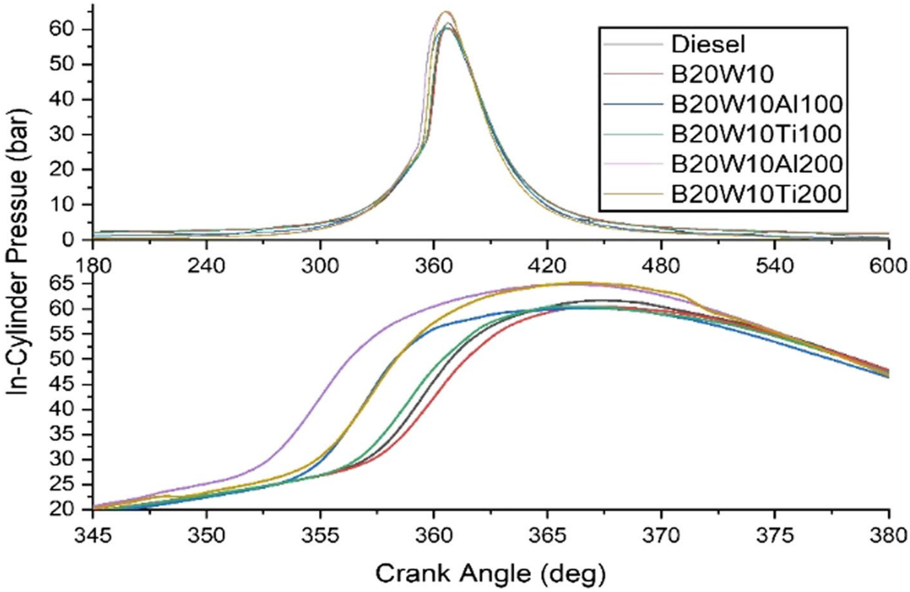

Fig. 14 Variations in-cylinder pressure for all testing fuels along with the crank angle

combined reaction of water particles and nanoparticles at the same time as the combustion phenomenon (Sobhani et al., 2014b). Primarily, the share of water droplets in nano-emulsified fuel acts as an ignition delay reactor. Whereas the presence of nanoparticles in nano-emulsified fuel works as a catalytic reactor throughout the combustion stage.

4 Conclusions

In this paper, a single-cylinder LHR diesel engine is tested with net diesel and four fuel samples such as B20W10Al100, B20W10Ti100, B20W10Al200, and B20W10Ti200. For validation purposes, the results obtained with nano-emulsified biodiesel were compared with net diesel under the same experimental setup. The experimental analysis demonstrates some interesting observations which are mentioned below:

- It was found that the maximum BTE obtained is 32.59% for B20W10Al200 at maximum load it is around 13.69% higher than the pure diesel operation.
- A low heat release rate was observed for the B20W10 fuel sample in comparison to the rest of the fuel samples.
- It was found that the BSFC for diesel and B20W10 is quite higher than the rest of the test fuels. And noted the lower BSFC for B20W10Al200.
- The drastic reduction of HC emissions was noticed for nano-emulsified fuel samples compared to diesel fuel. The lowest HC emissions were observed for B20W10Al200; it is around 55.35% lower than diesel operation.
- The use of different concentrations for Al_2O_3 and TiO_2 in emulsified fuels has shown considerably lower CO emissions. Furthermore, emulsified tested fuel B20W10Al200

has recorded significantly lesser CO emission. It is about 33.03% lower than the diesel operation.

- And also observed the significant reduction of NO_X emissions for the emulsified fuel samples. Among all the emulsified samples B20W10Al200 showed the lowest NO_X.
- It was noticed that B20W10Al200 has more cylinder pressure as compared to the rest of the test fuel

4.1 Future scope

There is huge scope in future to work on in this presented research work. Future work coziest of a new dimension and a new approach to deal with a specific area or stream. The following idea could be touched as part of future work:

i. It could be motivating to study comparative study of different coating materials as TBC for engine application.
ii. The way of consideration of samples of nanoparticles could be also changed in point of a greater number of different materials and quantities as Nano-emulsified biodiesel.

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