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Sustainability of Aluminium Oxide Nanoparticles Blended Mahua Biodiesel to the Direct Injection Diesel Engine Performance and Emission Analysis

Rastogi, P. M.[1*], Kumar, N.[1], Sharma, A.[2], Vyas, D.[3] and Gajbhiye, A.[4]

1. Department of Mechanical Engineering, Sir Padampat Singhania University, Udaipur, P.O. Box-313601, Rajasthan, India
2. Department of Mechanical Engineering, G L Bajaj Institute of Technology and Management, Greater Noida, P.O. Box-201306, UP, India
3. Department of Chemistry, Sir Padampat Singhania University, Udaipur, P.O. Box-313601, Rajasthan, India
4. Department of Biotechnology, Sir Padampat Singhania University, Udaipur, P.O. Box-313601, Rajasthan, India

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ABSTRACT: The study investigates the effect of aluminium oxide nanoparticles as an additive to *Madhuca Indica* (mahua) methyl ester blends on performance, emission analysis of a single-cylinder direct injection diesel engine operated at a constant speed at different operating conditions. The test fuels are indicated as B10A0.2, B10A0.4, B20A0.2, B20A0.4 and diesel respectively. The results indicate that the brake thermal efficiency for aluminium oxide nanoparticles blended biodiesel increases slightly when compared to the mineral diesel. The carbon monoxide (CO), unburnt hydrocarbon (HC) and smoke emission marginally decrease as compared to mineral diesel. Oxides of nitrogen (NOx) emissions are minimum for the aluminium oxide nanoparticles blended mahua methyl esters. Higher cylinder gas pressure and heat release rate were observed for aluminium oxide nanoparticles blended mahua methyl ester. From the study, the blending of aluminium oxide nanoparticles in biodiesel blends produces a most promising results in engine performance and also reduces the harmful emission from the engines.

Keywords: nanoparticles; madhuca indica oil; blends; brake thermal efficiency.

INTRODUCTION

The developing countries are in the process of utilizing the energy available in their countries. Most of the advancement is related to the automotive sector due to the demand of the consumers (Aalam et al., 2015; Acharya et al., 2017; Agarwal et al., 2008; Akbar et al., 2009; Amini et al., 2017). Biodiesel is one of the alternative to the petroleum products which can be produced from various resources (Azad et al., 2015; Bora & Saha, 2016). The feedstock available for the production of biodiesel are in abundant quantity with relation to the non-edible oils which is more in country India. Among the non-edible oils, *Madhuca Indica, Jatropha Curcas, Pongamia Pinnata, Calophyllum Inophyllum* etc. are the available feedstock's consisting of better properties for their conversion to the biodiesel (Singh

* Corresponding Author Email: rastogipankaj021@gmail.com

et al., 2017). The *Maduca Indica* (Mahua) belongs to species of *sapotaceae*. It is an Indian tropical tree found across the northern part. It grows 20 meters in height and grows at a rapid pace (Acharya et al., 2017; Senthil et al., 2016).

Based on the literature examined in detail, an improvement in the amount of brake thermal efficiency and reduction in emission is observed by the application of biodiesel in a diesel engine. But, an increase in the NO_x was observed with respect to their usage (Aalam et al., 2015; Sadhik Basha & Anand, 2011). The increase in the biodiesel amount was related to the oxygen content availability in the biodiesel which results in proper combustion enhancing the temperature rise during the emissions and deliver higher NO_x content. With reference to the application of biodiesel to the diesel engine, it contains some of the disadvantages which are related to their properties including higher viscosity, less volatility, higher molecular weight and higher pour point in comparison to the diesel fuel (Aalam et al., 2015). To cope up with the issues of the biodiesel, recent investigations reported about the fuel alterations by implementing prospective nanoparticles like titanium dioxide, copper oxide, magnesium oxide, and aluminium dioxide to enhance their properties. The application of the nanoparticles to the biodiesel has several advantages including short ignition delay, complete combustion, higher energy density and less emission of the pollutants (Hosseini et al., 2017; Saxena et al., 2017). Very few works have been addressed so far by including the feasible nanoparticles with the biodiesel to enhance the performance, and to reduce the harmful emissions from the diesel engine. Jung et. al. (Jung et al., 2005) reported the application of cerium oxide as an additive to the diesel. The decrease in the amount of ignition delay period and no existence of the soot emissions were observed. They have also obtained an improvement in the amount of oxidation rate. Kao et al. investigated the impact of aluminium oxide with diesel fuel. Reduction in the amount of BSFC, NO_x, and smoke emissions are the significant points observed during their study. Arul Mozhi Selvan et al. (Selvan et al., 2009) observed an improvement in the brake thermal efficiency with a remarkable decrease in HC and NOx emissions when cerium oxide nanoparticles were used as additives in the diesel-biodiesel blends. Sajith et al. (Sajith et al., 2010) explored the effect of cerium oxide on the performance of biodiesel while implementing in a diesel engine. An increase in the amount of viscosity and flash point of biodiesel was found with the implementation of the nanoparticles. Aalam et al. (Aalam et al., 2015) examined the aluminium oxide nanoparticles blended biodiesel in diesel engine and determined that marginal increase in the brake thermal efficiency, reduction in HC, CO, smoke emissions but a slight increase in NOx. Karthikeyan et al. (Karthikeyan et al., 2016) observed that the effect of cerium oxide in the biodiesel blends on diesel engine, increases the brake thermal efficiency and heat release rate and also reduces the brake specific fuel consumption. Mehta et al. (Mehta et al., 2014) examined the Combustion attributes, engine emission and performance parameters of a diesel engine utilizing nano fuels which were prepared through sonicating of aluminium and boron nanoparticles in base diesel with a span as a surfactant for stable suspension. The specific fuel consumption was diminished, CO, HC emissions declines and peak cylinder pressure diminishes at elevated load conditions.

Nano metal oxide additives are stated to be effective in lessening diesel emissions. The metal-based additives decreases the engine pollution emissions and fuel utilization values. Since the aluminium is in the nanometer range, it has the greater surface area and elevated activity to raise the combustion (Saxena et al., 2017). The aluminium oxide based nanoparticles are a suitable candidate for their application as an additive to the biodiesel. The aim of this study is to consider the effect of diesel-mahua methyl ester-aluminium oxide nanoparticles blends on engine performance and exhaust emissions in a single-cylinder direct injection diesel.

MATERIAL AND METHODS

Raw mahua oil was purchased from the local vendor of New Delhi City, India. Further, the transesterification process was applied to obtain the desired biodiesel while utilizing KOH as a catalyst as mentioned in the previous studies (Abedin et al., 2014; Aghbashlo et al., 2017; Al-Hamamre & Al-Salaymeh, 2014; Ashok et al., 2017). The KOH was used as the catalyst during this process. The base catalyst potassium hydroxide and methanol were mixed with oil in a round bottom flask and then the mixture was stirred for 1 - 1.5 hrs up to 60°C. The optimum conditions for getting the maximum biodiesel yield are as follows: 6:1 molar ratio of alcohol to oil, catalyst concentration of 1%, 60°C reaction temperature and 60 minutes of reaction time. The reactants were allowed to settle for about six to eight hours and then, the biodiesel and glycerol were separated. It is also detected that the obtained biodiesel comprises of impurities such as methanol and KOH. Hot distilled water is used to wash the sample to get rid of the traces of methanol and KOH and again, it is heated at 120°C for 25 minutes. The various ratio of biodiesel is mixed with diesel to observe its solubility which is further monitored for 10 days and no signs of separation is recorded.

The nanoparticles were purchased from Sigma Aldrich, USA and the particle size was 80 nm as provided by the supplier. Nanoparticles usually have high surface contact area and thus, their surface energy will be high. In order to make nanoparticles to be stable in a base fluid, it should be developed for surface modification. To improve the stability of nanoparticles, the certyl trimethyl ammonium bromide was used as a surfactant and it makes a non-diffusive layer on the surface of the nanoparticles (Aalam et al., 2015; Aghbashlo et al., 2017; Ali et al., 2016; Amini et al., 2017). The magnetic stirrer was used to get a proper homogeneity of the nanoparticles with the biodiesel blends. To make the blends of the solution prepared, ultrasonication process was applied using utrasonicator having 24 kHz frequency with 1 hour operating time. This ultrasonication is the best technique for better dispersion of the particles and also makes better uniform blends. The test fuels are designated as B10A0.2 (90% diesel, 10% biodiesel, and 0.2 gm nanoparticles), B10A0.4 (90% diesel, 10% biodiesel, and 0.4 gm nanoparticles), B20A0.2 (80% diesel, 20% biodiesel, and 0.2 gm nanoparticles), and B20A0.4 (80% diesel, 20% biodiesel, and 0.4 gm nanoparticles). The purpose of choosing these blends was related to their performance improvement and reduction in emissions of the diesel engine. The properties are evaluated based on the ASTM standard and the same has been described in Table 1.

Table 1. Properties of the fuels used for the test

S. No.	Properties	*Madhuca Indica* Methyl Esters	Diesel	B10A0.2	B10A0.4	B20A0.2	B20A0.2
1	Kinematic Viscosity @ 40°C (mm^2/s)	5.21	4.1	4.38	4.35	4.49	4.42
2	Density @ 15°C (kg/m^3)	889	837	848	853	858	862
3	Calorific Value (kJ/kg)	40302	42378	41783	41823	41908	41924
4	Flash Point (°C)	173	51	65	63	59	56
5	Pour Point (°C)	4.3	-17.3	-14.78	-14.78	-15.87	15.87

The schematic image of the engine is shown in Figure 1. This test engine has been supplied by Kirloskar Ltd. The engine is connected to a computer employed with engine software designed by Legion brother's agency (Aghbashlo et al., 2017; Ashok et al., 2017; Atabani et al., 2013; Atadashi et al., 2013; Canakci et al., 2009). Initially, the engine was running on neat diesel for 30 minutes before changing the mode of the fuel supplied until the temperature of the lubricant rose to around 80°C to maintain steady-state condition. Table 2 represents the technical specifications of the engine. Originally test engine is designed for diesel fuel having injection timing 23°bTDC and 180 bar fuel injection pressure. The experimental observation was taken three times and the average value was considered for the evaluation. The engine response parameters BTE, BSFC, CO, HC, NO_x, smoke opacity was obtained with the help of the AVL Di 444-gas analyser. The engine was warmed up until the operating temperature was stabilized. Then the fuel consumption, combustion data, exhaust emissions, and smoke opacity were measured. The technical specification, accuracy and percentage uncertainty of exhaust engine response are mentioned in Table 3.

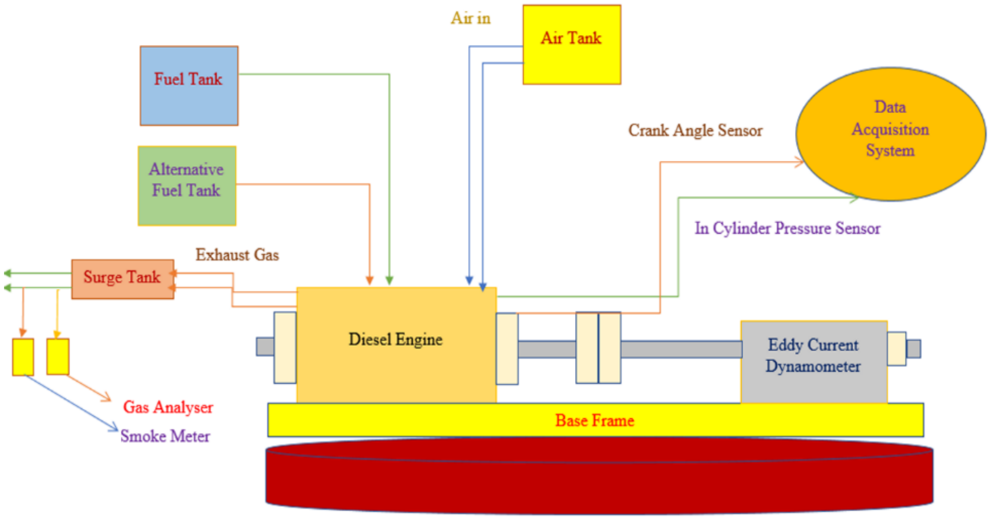

Fig. 1. Schematic image of the diesel engine set up for the test

Table 2. Diesel engine specifications

Make	Kirloskar
Type	4S, DI diesel engine
Bore and Stroke, mm	87.6 and 110 respectively
Capacity, Litre	0.661
Compression ratio	17.5:1
Loading	Eddy current dynamometer (water cooled)
Rated power	5.2 kW at 1500 rpm
Crank angle sensor	Resolution 1°, speed 5500 rpm with TDC pulse
Inlet valve open, °bTDC	4.5
Inlet valve closed, °aBDC	35.5
Exhaust valve open, °bBDC	35.5
Exhaust valve closed, °aTDC	4.5
Fuel injection timing, °bTDC	23
Fuel injection pressure, MPa	18
Starting	Manual cranking
Lubrication	Forced

Table 3. Technical specifications and accuracy of AVL Di Gas 444 gas analyser

Measurement	Range of Instrument	Accuracy achieved	% uncertainty
Unburnt Hydrocarbon (UHC)	0-20,000 ppm Vol	<200 ppm volume ±1 ppm volume >200 ppm % Vol: ±1%	±0.2
Warm up time	10 min. (self-controlled) at 25°C operating temperature		
Response time	Within 10 seconds for 90 % instrument response		

RESULTS AND DISCUSSION

Figure 2 shows the variation of the brake thermal efficiency with brake power. The brake thermal efficiency of the engine was enhanced with an increase of aluminium oxide nanoparticles quantity in the blends at all the brake power. Around 1.7%, 2.5%, 2.9% and 3.6% increase in the amount of BTE was observed at B10A0.2, B10A0.4, B10A0.2 and B10A0.4 samples respectively. The brake thermal efficiency for B20A0.4 blend is slightly higher when compared to other nanoparticles blends and mineral diesel. This could be attributed owing to the encapsulation of nanoparticles in biodiesel blend which gives the secondary atomization prompt after the essential micro explosion occurrence of mixing fuel. The occurrences of nanoparticles in the biodiesel blends promote complete combustion (Jung et al., 2005). This is owing to reduced physical ignition delay, high evaporation rate and higher flame temperature of nanoparticles lead to improve the efficiency.

The variation in in-cylinder pressure with respect to crank angle for mineral diesel, biodiesel blend, nanoparticles blended biodiesel samples are shown in Figure 3 at brake power conditions. From the plot, the in-cylinder pressure increases with an increase in nanoparticles in biodiesel blend (Rao & Anand, 2016). The improvement in cylinder pressure was attributed to greater contact surface area of nanoparticles and abundant intrinsic oxygen content of biodiesel. Moreover, improved air and fuel combination additionally encourages the quick burning of fuel inside the cylinder.

Figure 4 presents the variation of heat release rate with respect to crank angle. The nanoparticles addition to blend promotes the complete combustion which prevents the carbon deposit on the cylinder wall (Aalam et al., 2015). From the plot, it is clear that the heat release rate for B20A0.4 was higher as compared to other blends and diesel. The nanoparticles with biodiesel blends give elevated heat release rates in comparison that of neat diesel. This increment is owing to improvement in premixed combustion phase. The inclusion of nanoparticles abbreviates the ignition delay because of improved atomization of fuel and appropriate air-fuel combination. A comparable explanation for lessening in ignition delay was conferred by Basha et al. (Basha & Anand, 2012) when working with CNT nanoparticles.

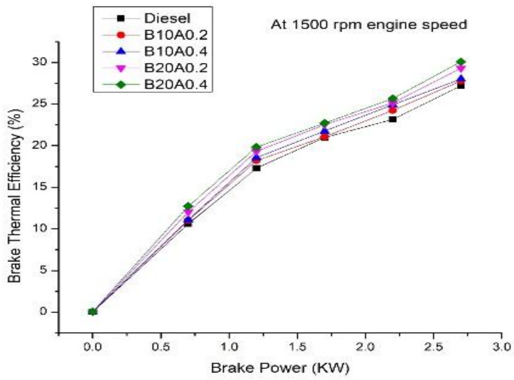

Fig. 2. Variation of the brake thermal efficiency with respect to the brake power

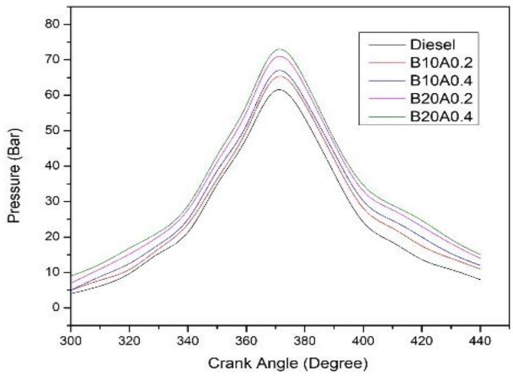

Fig. 3. Variation of cylinder pressure with crank angle for all the fuel blends

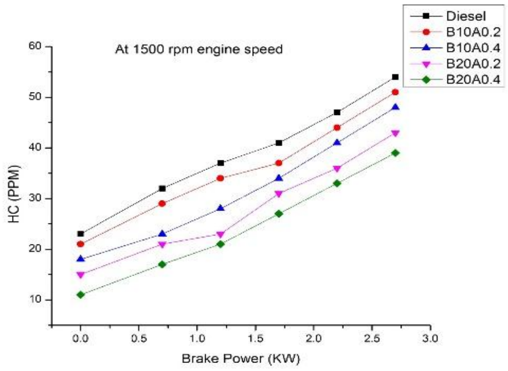

Fig.4. Variation of the hydrocarbon with respect to the brake power

The variation of hydrocarbon (HC) emissions with brake power for different fuel blends at various brake power conditions are presented in Figure 5. Unburned hydrocarbon (HC) is also a significant constraint for determining the emission behaviour of the engine. From the graph, the HC emission decreases with an increase in aluminium oxide nanoparticles with biodiesel blends. HC emission is considerably reduced with the addition of nanoparticles to fuel blends.

The inclusion of nanoparticles with biodiesel blends acts as an oxidizing catalyst quickens the flame propagation inside the cylinder, which reduces the carbon activation temperature and advances further entire burning. Every one of these elements primarily restrain the HC emissions from nanoparticles mixed biodiesel blends. However the expansion of nanoparticles with biodiesel blends found to lesser the hydrocarbon emissions in comparison that of diesel, this diminishment is primarily because of greatly oxygenated structure and high cetane number of biofuels (Aghbashlo et al., 2017; Rao & Anand, 2016).

The variation of carbon monoxide (CO) emission with brake power for different fuel blends are illustrated in Figure 6. From the graph, it is clear that there is a significant reduction in CO emissions for aluminium oxide nanoparticles blended biodiesel blends than compared with mineral diesel. The inclusion of nanoparticles advances quick burning reactions, which prompts the decrease in the ignition delay period. Furthermore, the appropriate air-fuel combination and enhanced fuel burning brought more complete burning, which gives considerable lessening in CO emission contrasted with that of fuel without the inclusion of nanoparticles. This decrease in CO emission can be attributed owing to higher oxygen content accessible in the molecules of biodiesel and the catalytic impact of nanoparticles which in total enhances the burning efficiency (He, 2016; Saxena et al., 2017).

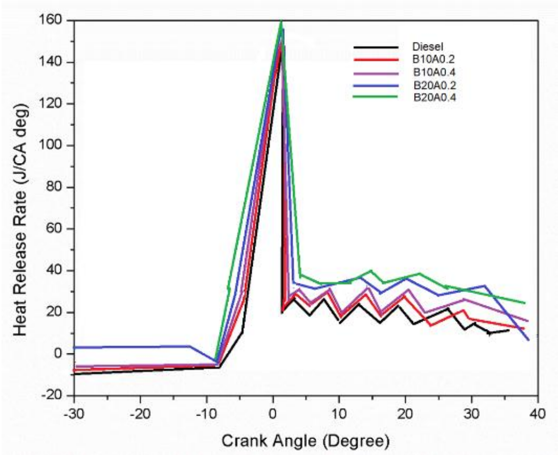

Fig. 5. Heat release rate with crank angle for the test fuels

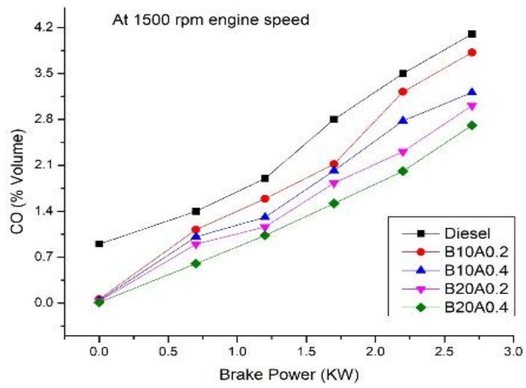

Fig. 6. Variation of the carbon monoxide at different brake power for the fuel blends

There are number of variables on which emission of NO_x depends including fuel properties, the temperature inside the combustion chamber, and working conditions of the engine. Figure 7 shows the variation of NO_x with respect to the brake power for different blends. With the inclusion of the nanoparticles as an additive to the biodiesel blends, NO_x decreases with comparison to the diesel. Biodiesel contains more amount of oxygen content (Abedin et al., 2014; Acharya et al., 2017). This extremely oxygenated fuel gives improved combustion and elevated heat release rates which were brought at elevated cylinder temperatures. Furthermore, advancement in fuel injection for biodiesel was happened owing to higher bulk modulus which additionally increases the NOx emission level. At that point, the inclusion of aluminium oxide nanoparticles could increase the surface area and reduces the ignition delay, on one hand, the presence of aluminium oxide nanoparticles help the active reaction of hydrocarbon with oxygen and reduces the reaction of nitrogen with oxygen on the other hand, which reduces the NO_x formation in the cylinder. These outcomes presented in this study coordinate with the investigational findings of the study conducted other researchers (Basha & Anand, 2012; Sadhik Basha & Anand, 2011).

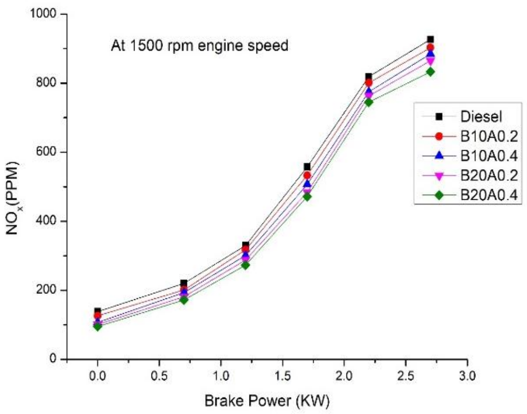

Fig. 7. Variation of the nitrogen oxide with respect to the brake power

The variation in smoke opacity with brake power for different blends is presented in figure 8. From the plot, it is ascertained that there is extensive lessening in the smoke density for aluminium oxide nanoparticles blended biodiesel fuel when in comparison with mineral diesel. This may be due to the presence of oxygen in the nanoparticles, which influence the reduction in smoke emissions due to better combustion. The smoke density gradually increases in all fuel blends for all loads. It was also observed that the smoke density diminishes with an increase in the concentration of nanoparticles in the fuel blends. The addition of nanoparticles in the biodiesel blends may result in a higher evaporation rate, shorter ignition delay period and enhanced ignition characteristics (Kumar Patel & Kumar, 2017; Vairamuthu et al., 2016).

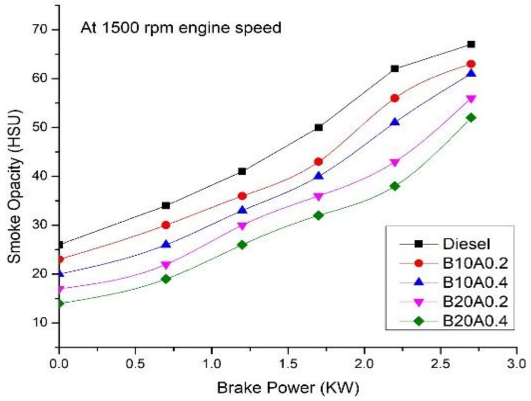

Fig. 8. Variation of the smoke opacity with brake power for all fuel blends

CONCLUSION

The effect of diesel-biodiesel-aluminium oxide nanoparticles blends on engine performance, and exhaust emission analysis was investigated. The following outputs are obtained based on the study conducted.

- The brake thermal efficiency of nanoparticles blended biodiesel B20A0.4 shows a considerable improvement when in comparison to that of other biodiesel-nanoparticle blends and mineral diesel. This might be attributed to the superior combustion characteristics of nanoparticles.
- The in-cylinder gas pressure for aluminium oxide nanoparticles

- blended biodiesel increases with the increase of nanoparticles fraction in the blend. This could be a result of their elevated catalytic activity owed to their increased surface area to volume ratio.
- There is a marginal reduction in HC, CO and smoke emissions for nanoparticles in the biodiesel blends (B20A0.2 and B20A0.4) when compared to mineral diesel. Because nanoparticles are an oxidation catalyst which leads to complete combustion and shorter ignition delay.
- When nanoparticles are blended with biodiesel blends, a decrement in the amount NO_x emissions were observed. The inclusion of aluminium oxide nanoparticles increases the surface area and reduces the ignition delay, on one hand and the presence of aluminium oxide nanoparticles help the active reaction of hydrocarbon with oxygen and reduces the reaction of nitrogen with oxygen on the other hand, which reduces the NO_x formation in the cylinder.

In general, it has been concluded that aluminium oxide nanoparticles is efficient and enhances the engine performance, and reduces the exhaust emissions of the diesel engine. Additionally, it is clearly understood that the aluminium oxide nanoparticles will be the most promising additive for biodiesel.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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