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Performance Enhancement of Common-Rail Diesel Engine using Al_2O_3 and Fe_3O_4 Nanoparticles Blended Biodiesel

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Abstract - ***This paper reports on the effect of nanoparticles as additive to the biodiesel blend fuel and its effects on a single cylinder CRDI diesel engine coupled with a data acquisition system. Mahua methyl ester at the ratio of 20% (MME20) taken as fuel for diesel engine. Aluminium oxide (AONP) and Iron oxide (IONP) nanoparticles are used as catalyst with MME20. The nanoparticles added to MME20 in different proportions (40ppm and 80ppm) using an ultrasonicator and a mechanical homogenizer. The aluminium oxide and iron oxide nanoparticles acts as an oxygen donating catalyst and donates oxygen for the oxidation of unburned hydrocarbons and carbon monoxide. It was observed significant improvement in brake thermal efficiency and heat release rate due to the influence of the nanoparticles addition in MME20 fuel. It was observed that nanoparticles blended fuel exhibits a significant reduction in specific fuel consumption and exhaust emissions at all operating loads.***

Key Words: *Aluminium oxide nanoparticles (AONP), Iron oxide nanoparticles (IONP), Oxygen donates catalyst, Performance, Combustion, Emissions.*

1. INTRODUCTION

Biodiesel, an alternative fuel, is prepared from biological sources such as vegetable oils and animal fats. It is recyclable and non-toxic has low emission profiles and so it is environmentally beneficial [1]. India is importing more than 70% of its fuel demand and expenses an huge amount of money on fuel. Biodiesel is attaining more important as a smart fuel due to the fast depleting fossil fuel resources. The properties of biodiesel are almost similar to the diesel fuel; thus, it becomes a potential alternative to diesel fuel [2,3]. Fatty acids may be used to prepare biodiesel fuel. Thus, any agriculture lipid should be a substrate for the production of biodiesel. The use of vegetable oils for biodiesel production has recently been of big concern. The recent focus is the use of non-edible vegetable oil and waste products of edible oil as the feedstock for biodiesel production. The purpose of the transesterification or catalytic cracking process is to lower the viscosity of the raw oil [4]. Nanometal oxide additives are reported to be successful in reducing diesel emissions. The metal based additives reduce diesel engine pollution emissions and fuel consumption values. The reason for emission drop is that the metal reacting with water to create hydroxyl radicals, which improve soot oxidation, or by direct reaction with the carbon atoms in the soot, thereby lowering the oxidation temperature [5-11]. Aluminium nanopowder can react with water at high temperatures and produce hydrogen, promote the combustion of the fuel. Because the aluminium is of nanometer size, it has more surface area and higher activity to decay the hydrogen from water and increase combustion [12-14]. Karthikeyan et al. [15] found that the combustion characteristics improved by the lighter surface to volume ratio of nanoparticles, which allowed most amount of fuel to react with the air. It leads to enhance the brake thermal efficiency. By and large, it is observed that the minimum CO and HC were measured with the use of ZnO blend.The aluminium nanoparticles can react with water at temperatures from 400 to 650˚C to generate hydrogen [16-17]. Sadik basha et al. [18] have conducted a number of experiments in direct injection diesel engine using alumina nanoparticles and carbon nanotubes as additive with biodiesel and diesel fuels and observed an appreciable increase in the brake thermal efficiency and reduction in harmful pollutants compared to that of neat biodiesel and neat diesel. The aluminium powder is a familiar ingredient for explosive formulations. Latest technology allowed the production of aluminium particles of nanosize. These particles exhibits bizarre thermal behavior that was thought to be connected with stored internal energy [19,20]. In this paper the effect of aluminium oxide and iron oxide nanoparticles with mahua methyl ester blend was studied in CRDI diesel engine.

2. MATERIALS AND METHODS

2.1 Biodiesel Production

Paragraph One liter of Mahua oil is heated in an open beaker to a temperature of 100-120˚C to remove water contends present in vegetable oil followed by filtration of raw vegetable oil. The raw oil is processed under base catalyzed transesterification method where it is mixed with 200 ml of methanol and 7gms of sodium hydroxide (NaOH) pellets. The mixer has been kept on a hot plate magnetic stirring arrangement since 1-1.5 hours up to 60̊C and then it is allowed to settle down for about 5-6 hours to obtain methyl ester and glycerol. The methyl ester obtained in the process is further washed with distilled water for 2-3 times for the removal of acids and heated above 100ºC to separate the moisture content present in the methyl ester. Hence, the pure Mahua methyl ester is obtained.

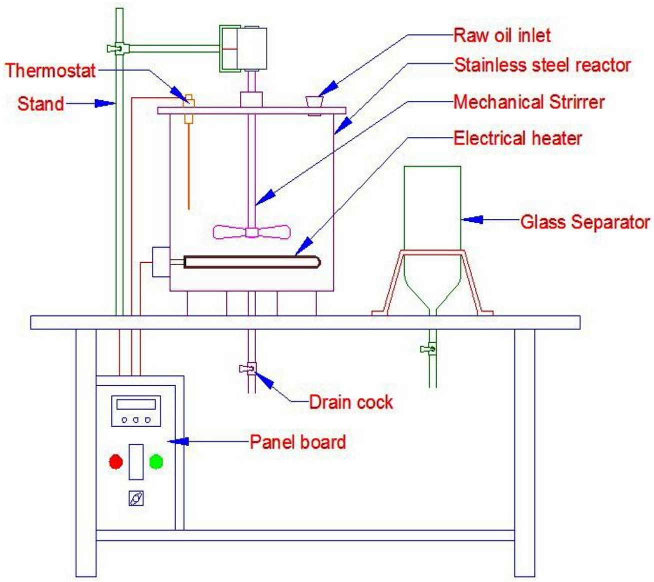


Fig. 2 Schematic diagram of Biodiesel Plant

Fig. 3 Pictorial view of Mahua biodiesel and its blend (MME20)

2.2. Preparation of fuel blend

For the blending of aluminium oxide nanoparticles in biodiesel, taken a sample of MME20 biodiesel say 1 lit and then 0.04 g of aluminium oxide in the nanoparticles form is added to make the dosing level of 40 ppm. Consequently, to increase the dosing level of 80 ppm, increase the level to 0.08 g/l, respectively. Cetyl trimethylammonium bromide (CTAB) is a cationic surfactant and it create an envelope on the surface of the nanoparticles. After the addition of nanoparticles, it is shaken well. And then it is poured into mechanical Homogenizer where it is agitated for about 45 min in an ultrasonic shaker to making uniform suspension.

2.3 Properties of biodiesel blends

The physical and chemical properties of biodiesel were determined by standard methods and shown in Table 1. In order to measure the properties of the biodiesel and the blends, the test methods were used as follows. Density is an important property of biodiesel. Density is mass per unit volume of any liquid at a given temperature. Density measurement was carried out using a hydrometer at a temperature of 312 K. The flash point temperature of biodiesel fuel is the minimum temperature at which the fuel will ignite on application of an ignition source. Flash point varies inversely with the fuel's volatility. Fire point is the lowest temperature at which a sample will continue burning for 5 s. Flash points of the samples were measured in the temperature range of 50-190˚C by an automated Pensky–Martens closed-cup apparatus. The calorific value of a fuel is the thermal energy released per unit quantity of fuel when the fuel is burned completely and the products of combustion are cooled back to the initial temperature of the combustible mixture. It measures the energy content in a fuel. The calorific value of biodiesel and its blends was measured in a bomb calorimeter according to ASTM D240 standard method. Viscosity is a measurement of the internal fluid friction of oil to flow, which tends to resist any dynamic change in the fluid motion. Viscosity is measured by using Redwood Viscometer. The Redwood viscosity value is the number of seconds required for 50 ml of oil to flow out of a standard Viscometer at a definite temperature. The cetane number of the fuel is one such important parameter which is responsible for the delay period. Cetane number is defined as the percentage by volume of normal cetane in a mixture of normal cetane and a-methyl naphthalene, which has the same ignition characteristics as the test fuel, when combustion is carried out in a standard engine under particular operating conditions. A fuel with higher cetane number gives a lower delay period and provides smoother engine operation. Biodiesel has a higher cetane number than diesel because of its higher oxygen content.

Table 1 Properties of biodiesel sample

Description	Viscosity @40ºC (cSt)	Density @ 15°C (kg/m3)	Flash Point (°C)	Calorific value, (kJ/kg)	Cetane number
Diesel fuel	3	815	56	42,000	47
MME20	3.6	823.4	69	41,256	51

2.4 Properties of nanoparticles

The nanoparticles used for testing were commercially available in market (Supplier- Reinste Nano). The size of the crystals is very important in nano composites to evaluate the mechanical, and chemical properties [26]. Surface and morphological characterization of aluminium oxide nanoparticles was carried out using scanning electron microscopy. The SEM images showed that, most of the nanoparticles obtained from all the abated laser energies have spherical shape with a particle size of less than 100 nm [24]. The SEM of aluminium oxide nanoparticles is shown in Fig. 1 and iron oxide nanoparticles is shown in Fig. 2. Nanosized spherical shaped particles obtained were confirmed. The mean size of the aluminium oxide particles varies from 31.6 to 47.5 nm and mean size of iron oxide varies from 24-65 nm.

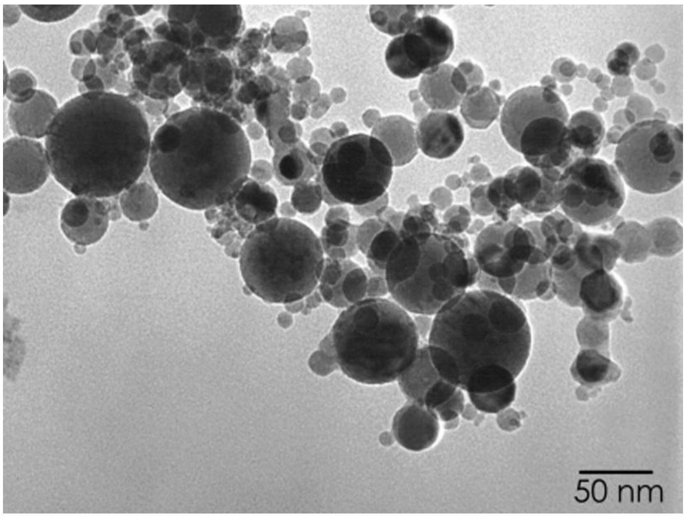


Figure 1 SEM of aluminium oxide nanoparticles (Given by supplier)

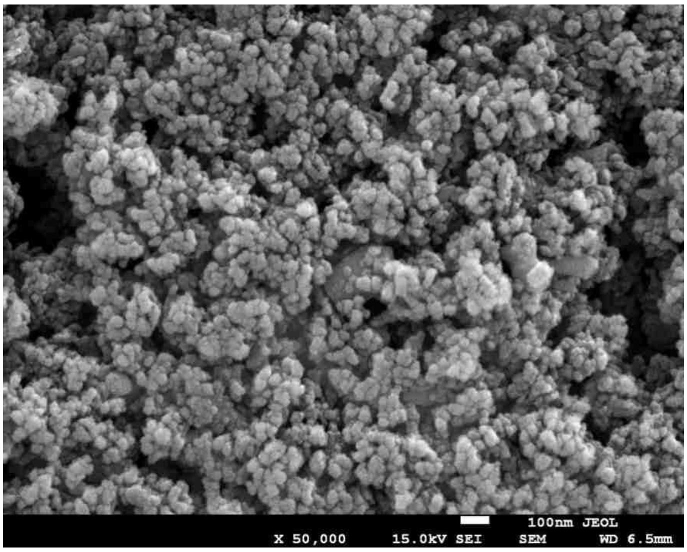


Figure 2 SEM of iron oxide nanoparticles (Given by supplier)

3. EXPERIMENTAL SETUP AND TEST PROCEDURE

Experiments were conducted on Kirloskar AV1, four stroke, single cylinder diesel engine assisted by common rail direct injection system. The rated power of the engine was 3.7 kW. The engine was operated at a constant speed of 1500 rpm with varying injection pressure from 250-500 bar to maintain the speed at different load condition. Thermocouple and a digital display were used to note the exhaust gas temperature. The Hartridge smoke meter was used for measuring of smoke emission. HC. CO and NOx emissions were measured using AVL di-gas analyzer. Parameters such as fuel consumption and emission characteristics such as NOx, HC and smoke were recorded. The performance of the engine was evaluated in terms of brake power, and specific fuel consumption from the above parameters. Details of the engine specification are given in Table 2 and injector specification given in table 3.

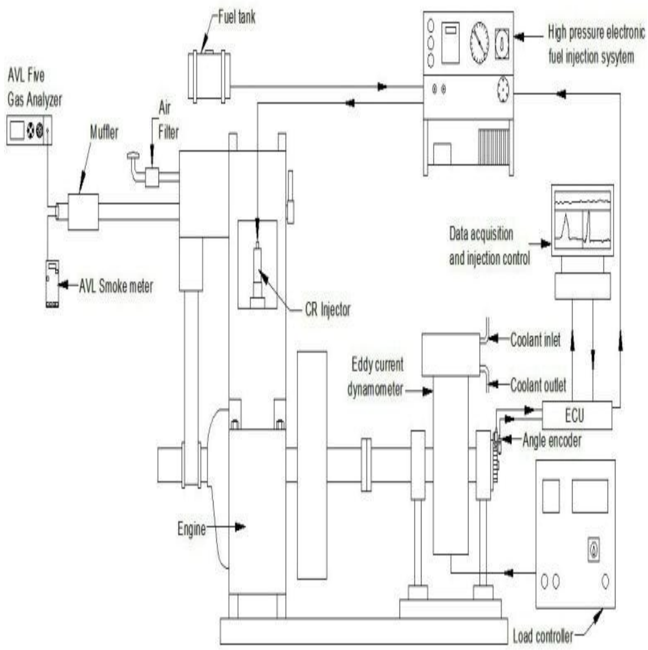
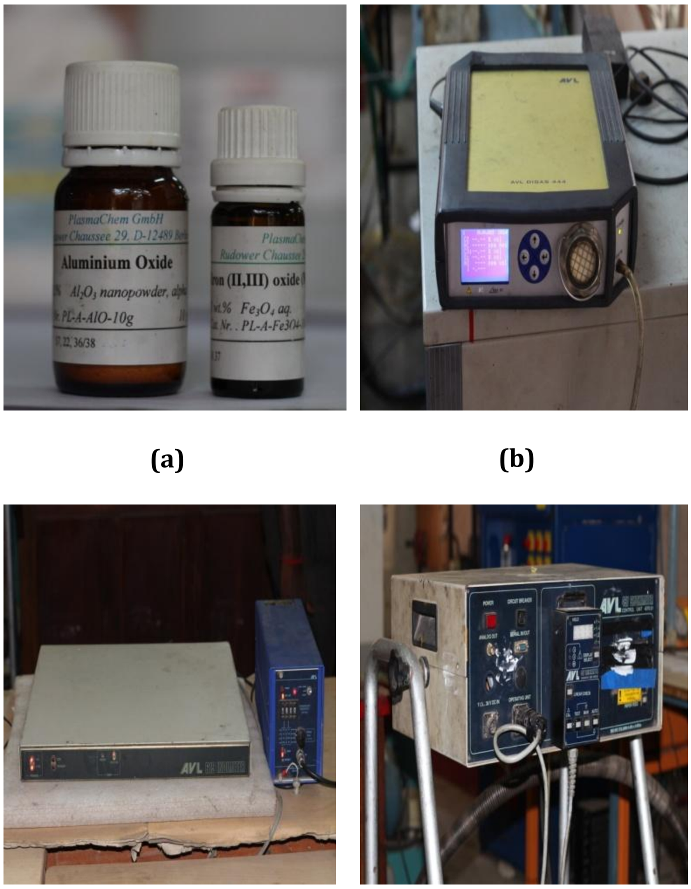


Figure 5. Engine set up with common rail fuel injection system



(a) (b)

(c) (d)

Fig. 6 (a) Nanoparticles samples (b) AVL Di-gas analyzer (c) AVL indimeter (d) AVL smoke meter

Table 1. Engine specification

Type	:	Vertical, water cooled, four stroke
Number of cylinders	:	One
Bore	:	80 mm
Stroke	:	110 mm
Compression ratio	:	17.5:1
Maximum power	:	3.7 kW
Speed	:	1500 rev/min
Dynamometer	:	Eddy current
Injection timing	:	23° (before TDC)
Injection pressure	:	250-500 kgf/cm^2

Table 2. Injector fuel system specifications

Fuel fed	**Units**	**Common rail**
Injection pressure	MPa	250-600 MPa
Number of nozzle holes	-	3
Nozzle hole diameter	mm	0.518
Start of injection	-	23° Before top dead center (BTDC)
Injection duration	μsec	750
Fuel injected	g/cycle	0.168 (at full load)

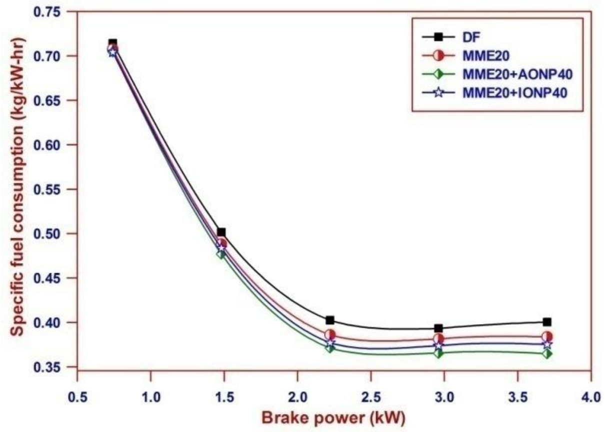
4. RESULTS AND DISCUSSION

The operation of the engine was found to be very smooth throughout the rated load, without any operational trouble for the aluminium oxide and iron oxide nanoparticles blended mahua methyl ester fuel blend. In the present section, based on the combustion data, cylinder pressure and heat release rate are plotted against crank angle. The performance attributes such as brake thermal efficiency, specific fuel consumption, and the emission parameters such as CO, HC, NOx, and smoke opacity are plotted against brake power.

4.1 Engine Performance Parameters

4.1.1 Specific Fuel Consumption (SFC)

Brake specific fuel consumption, which depends on the engine power as well as density and viscosity of the fuel. The variations of specific fuel consumption for the MME20 and, aluminium oxide and iron oxide nanoparticles blended MME20 at various loads have been depicted in Fig.3. It is observed that in both the cases 40 and 80ppm, AONP blended fuel shows a considerable decrease of SFC in comparison IONP blended fuels. The decrease in SFC can be due to the positive effects of nanoparticles on physical properties of the fuel and reduction of ignition delay period. Corresponding to brake power, the specific fuel consumption decreases with an increase in the dosing level of nanoparticles. At maximum load, the SFC of MME20 fuel was 0.39kg/kW-hr, when the nanoparticles added with MME20 in the fraction of 40 ppm the SFC becomes 0.38 and 0.37 kg/kW-hr for IONP40 and AONP40 respectively. The dosage of nanoparticles was increased into 80ppm with MME20, the SFC reduced to 0.36 kg/kW-hr for AONP80 case, and there is no change of SFC in the case of IONP80. From the figure it is clear that the AONP was reduce the SFC of the engine compared with IONP additive when using MME20 as fuel.



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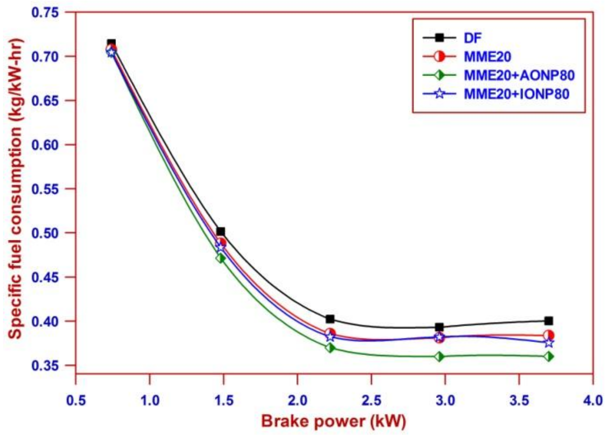
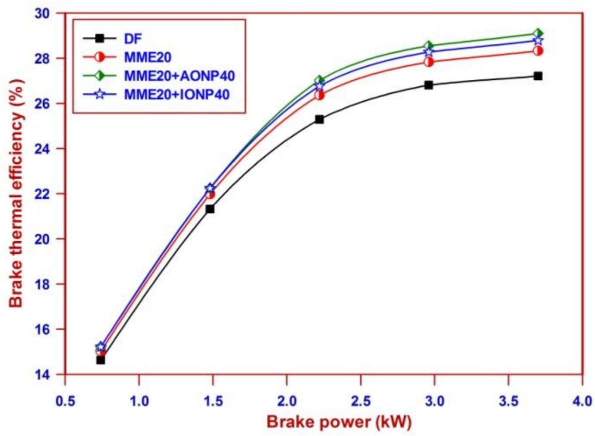


(b)

Fig. 1 Specific fuel consumption (a) at 40ppm nano additive (b) at 80ppm nano additive

4.1.2 Brake Thermal Efficiency (BTE)

Fig. 4 shows the variation of brake thermal efficiency with increasing load for two different concentrations of nanoparticles. The BTE of the nanoparticles blended MME20 was observed to be better, compared to MME20 and neat diesel. This could be attributed due to the better combustion characteristics of aluminium oxide and iron oxide nanoparticles. In general, the nanosized particles possess a high surface area and reactive surfaces that contribute to higher chemical reactivity to act as a potential catalyst [11]. In the case of AONP40+MME20 the BTE was increased up to 0.8%, but in the case IONP40+MME20 the BTE was increased upto 4.3%. There is slight increament of BTE in the cases of AONP80+MME20 and IONP80+MME20. The maximum BTE for AONP40+MME20 is 29.1% where it is 28.78% for IONP40+MME20 and 28.32% for MME20 at full load and 880 bar injection pressure. Where as it was 29.35 and 28.92% for AONP80+MME20 and IONP80+MME20 respectively. From the figure it was clear that the AONP was effective in increase the BTE compared with IONP.



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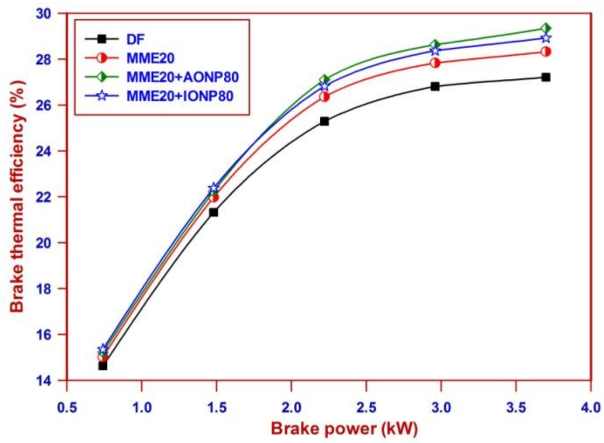


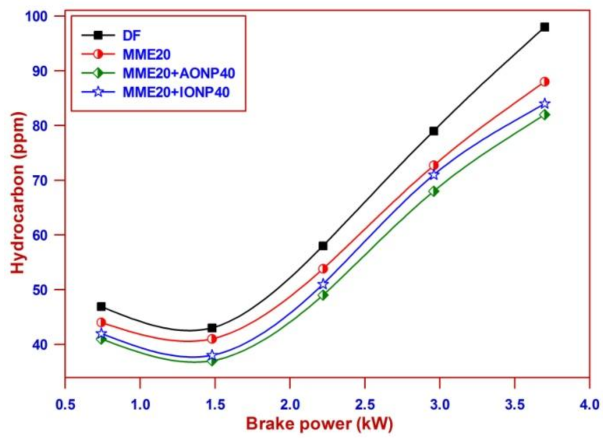
(b)

Fig. 2 Brake thermal efficiency (BTE) (a) at 40ppm nano additive (b) at 80ppm nano additive

4.2 Emission Parameters

4.2.1 Hydrocarbon Emission (HC)

Fig. 9 shows the variation of hydrocarbon emissions for 40 ppm and 80 ppm levels of aluminium oxide (AONP) and iron oxide nanoparticles (IONP) in Mahua biodiesel blend (MME20). Addition of nanoparticles increased the level of oxygen content in the biodiesel blend (MME20). However, oxygen content of fuel is the main reason for HC emission reduction and complete combustion of fuel [12]. Hydrocarbon emission is found to be considerably reduced with the addition of the nanoparticles to biodiesel blend. From the figure, it is seen that the HC emission reduced with the increase of nanoparticles dosing level with biodiesel blend (MME20). HC emission was 88, 84 and 82ppm for MME20, MME20+IONP40 and MME20+AONP40 blends respectively. Where as HC emission was 83 and 81 ppm for MME20+IONP80 and MME20+AONP80 blends.



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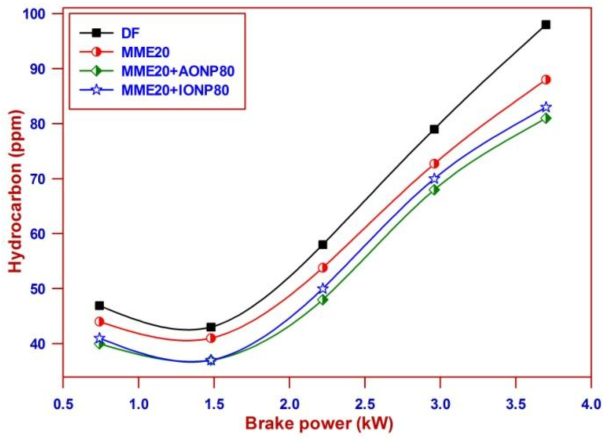
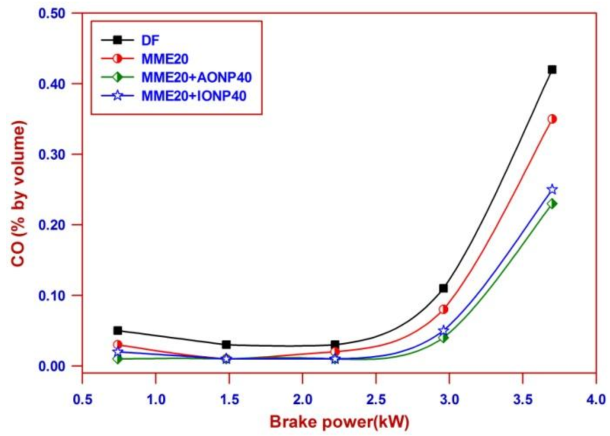


(b)

Fig. 3 Hydrocarbon Emission (HC) (a) at 40ppm nano additive (b) at 80ppm nano additive

4.2.2 Carbon monoxide Emission (CO)

The variation of carbon monoxide (CO) emission with brake power is shown in Fig. 5. The CO emission is increased marginal up to the brake power of 3 kW and then increases rapidly with higher load. The nonoparticles present in the biodiesel blend fuel promotes complete combustion, as compared to the base fuel (MME20), as metal oxide nanoparticles acts as an oxygen buffer and releasing oxygen depends upon the partial pressure of oxygen. From the graph it is found that the CO emission considerably reduced with the addition of nanoparticles with the MME20. The CO emission decrements are about 17% and 19% of the cases of MME20+IONP40 and MME20+AONP40 fuels, respectively at the full load of the engine. Where CO emission was reduced about 18% and 20% for MME20+IONP80 and MME20+AONP80 respectively. From the results it is clear that the AONP40 is effectively reducing the CO emission compared with IONP40 and there is no major reduction in CO, when the nanoparticles dosage was increased.



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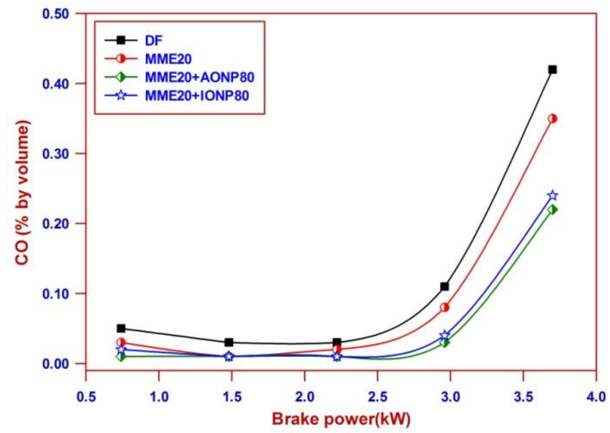


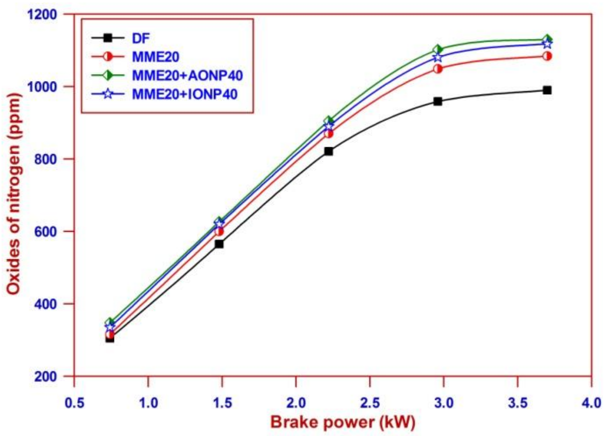
(b)

Fig. 4 Carbon monoxide Emission (CO) (a) at 40ppm nano additive (b) 80ppm nano additive

4.2.3 Oxides of Nitrogen (NOx)

Fig. 7 shows NOx emission with, and without the addition of nanoparticles on MME20. It can be seen that NOx gradually increased with addition of nanoparticles in all the cases. NOx emission mainly depends on temperature, the local concentration of oxygen and the duration of combustion during different combustion phases on the different combustion zones. By the addition of nanoparticles, which increases combustion duration that increases the NOx emission. The addition of nanoparticles to MME20 up to part load tends gradual increases of NOx emission, beyond that considerably higher NOx emission at maximum load were observed. NOx emission of MME20 without the addition of nanoparticles was 1080ppm and after addition of nanoparticles it will be increased. When the dosage of 40 ppm AONP, NOx emissions will be

1130ppm and for dosage of 40ppm IONP, NOx emissions will be 1118ppm. Increased in dosage level of nanoparticles further increased the NOx emission. It was 1140 and 1120ppm for MME20+IONP80 and MME20+AONP80 respectively.



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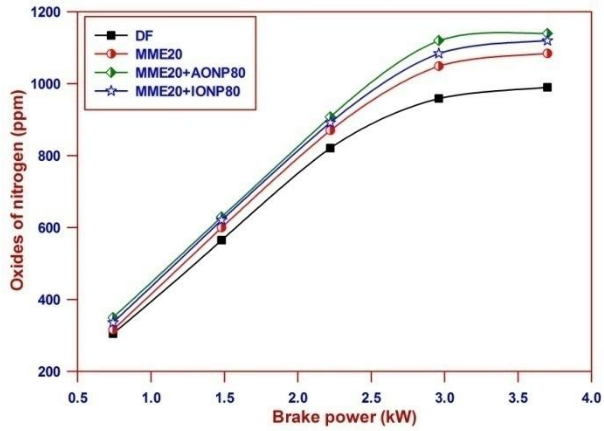
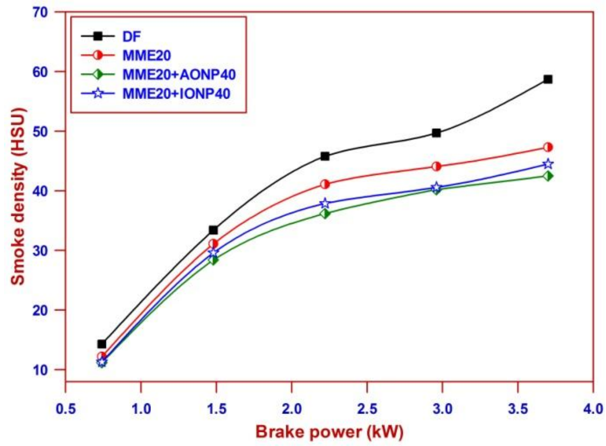


(b)

Fig. 5 Oxides of Nitrogen (NOx) (a) at 40ppm nano additive (b) 80ppm nano additive

4.2.4 Smoke Emission

Figure 9 shows the variation of smoke density with brake power for the Mahua methyl ester blend (MME20) and modified MME20. The nanoparticle blended fuels showed accelerated combustion due to the shortened ignition delay. Due to shortened of ignition delay, the degree of fuel–air mixing and uniform burning could have enhanced [13]. The smoke density of MME20 was decreased with the addition of nanoparticles by about 15-18%, especially at full load. This could be attributed to shorter ignition delay characteristics of nanoparticles blended fuels. It was also observed that the reduction in the smoke density increases with the increase of the concentration of metal oxide nanoparticles. The smoke emission was 47.3HSU for MME20 blend and it was 42.5, 44.5HSU for MME20+IONP40 and MME20+AONP40 fuels. Where as it was 44.5 and 45.8HSU for MME20+IONP80 and MME20+AONP80 fuel blends respectively.



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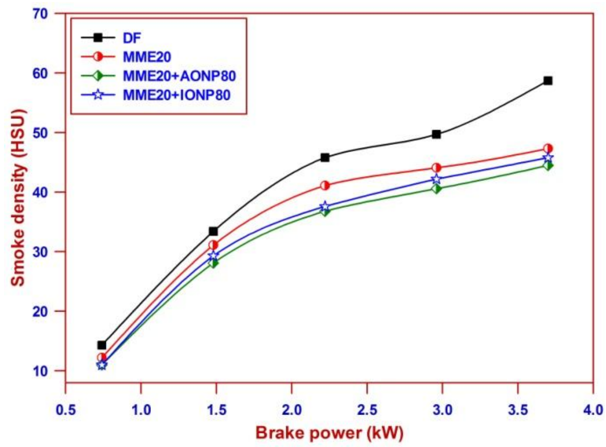


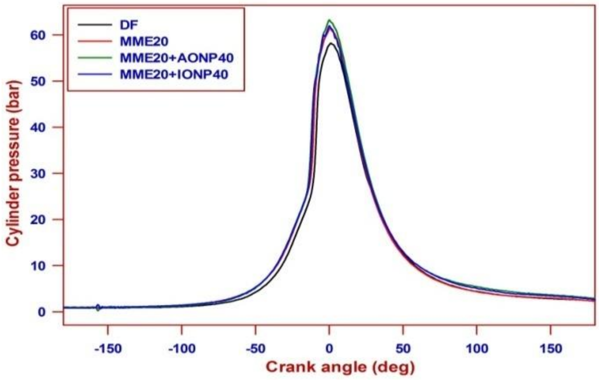
(b)

Fig. 6 Smoke Emission (a) at 40ppm nano additive (b) 80ppm nano additive

4.3 Combustion Parameters

4.3.1 Cylinder Pressure

Figure 9 shows that the in-cylinder pressure within the combustion chamber of the CRDI diesel engine running with nanoparticles blended mahua methyl ester blend (MME20) and sole diesel at a constant speed of 1500 rpm and constant fuel injection pressure of 880bar. From the figure it is seen that the pressure increasing significantly from 7° before TDC for 40ppm IONP blended MME20 and 8° before TDC for 40ppm AONP blended MME20 fuel. Further, there are no major changes in increase in dosage level of nanoparticles. The initial increase in pressure observed in the case of 80ppm AONP blended diesel fuel compared to the neat diesel fuel. The peak pressure is 64.70 bar in the case of MME20+AONP80 fuel blends, whereas the peak pressure is 62.04 bar for the MME20 blend at full load as shown in Fig. 8.



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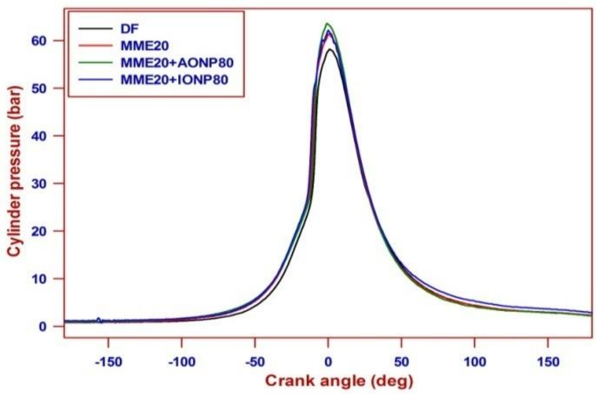
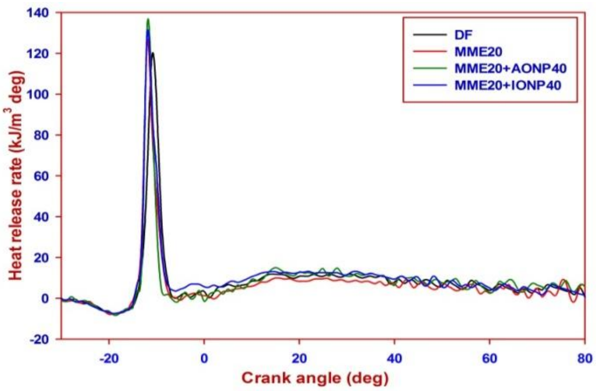


(b)

Fig. 8 Cylinder Pressure (a) at 40ppm nano additive (b) 80ppm nano additive

4.3.2 Heat Release Rate (HRR)

The variation of heat release rate with crank angle is shown in Figure 10. The addition of nanoparticles increases higher carbon combustion activation and hence promotes the complete combustion [8]. The results show that the heat release rate was found to be generally increased with the addition of metal oxide nanoparticles to biodiesel blend. This is due to premixed and uncontrolled combustion phase. The amount of heat release rate is 124.747, 132.828 and 137.938 kJ/m3deg for MME20, MME20+IONP40 and MME20+AONP40 fuel blends respectively. Whereas increasing the dosing level of nanoparticles tends to increase the heat release rate (HRR). From the figure it is clear that the AONP was improve the heat release rate compared with IONP.



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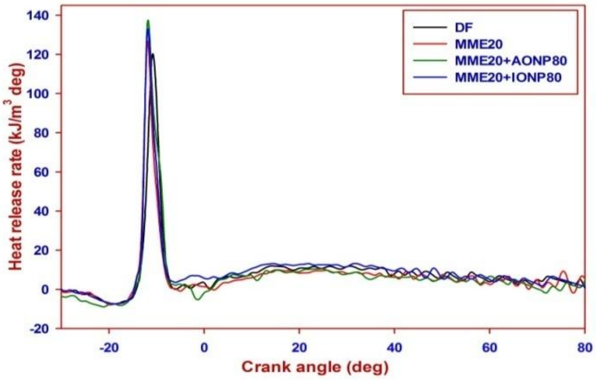

(b)

Fig. 9 Heat Release Rate (HRR) (a) at 40ppm nano additive (b) 80ppm nano additive

5. CONCLUSION

From the experiments carried out on the CRDI system assisted diesel engine fuelled with MME20, aluminium oxide and iron oxide nanoparticles blended MME20, the following conclusions can be drawn:

- Good improvement in brake thermal efficiency was observed with nanoparticles blended MME20 at optimized operating conditions. Especially AONP40 was effective in improvement of brake thermal efficiency compared with IONP40. There is no major improvement in BTE when the dosing level of nanoparticles was further increased.
- With the addition of nanoparticles to MME20 fuel, the level of harmful pollutants in the exhaust gases, such as HC, CO and smoke, was significantly reduced when compared to that MME20 and neat diesel. At the dosage of 40 ppm AONP, HC emissions will be 82ppm and the case of 40ppm IONP, it 84ppm.
- The smoke emission of MME20 was decreased on the addition of nanoparticles by about 15-18%, especially at full load
- AONP blended MME20 fuel blends showed higher cylinder gas pressure and heat release rate at optimized operating conditions.

Hence, AONP is efficient in improving performance and reducing the exhaust harmful pollutants compared with IONP, from the CRDI diesel engine when using MME20 as fuel.

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