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Influence of the aluminium oxide (Al2O3) nano particle additive with biodiesel on modified diesel engine performance

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ABSTRACT

Modification in the both base bio-fuel and engine design is highly distinctive to accomplish extent fuel conversion efficiency for the biodiesel operated diesel engine. In the present study, effect of aluminium oxide (Al_2O_3) (75 ppm) nanaoparticles on the performance of baseline (unmodified) and modified diesel engine is studied. The experimental results are compared with baseline engine run with sole 20% dairy scum biodiesel (B20) and petro-diesel. From the study, it is cleared that modified engine run with 75-ppm Al_2O_3 blended biodiesel has revealed the better performance than the baseline engine run with sole B20 fuel blend.

Keywords: Nano additive, diesel engine, engine modification, analysis

1. Introduction

Indian agriculture majorly using diesel engines for transportation and agricultural machinery as they exhibits the better thermal efficiency. Due to faster depletion and increased cost of the fossil fuels made the researchers to search novel alternative fuels for the diesel engines which promises the better performance. In this regard, the fuels derived from the bio-origin can be considered as sustainable fuels for the engines (H. Sharon et al. 2012). The biodiesel and ethanol fuels are getting more prominence day-by-day as they are biodegradable, nontoxic and reduces the harmful emissions (Manjunath channappagoudra et al. 2018). The reformulation of the biodiesel by adding nano particle (tamarind seed biodiesel) has shown the reduced CO and HC emissions. However, NOx emission is increased with addition of nanoparticles it could be because of nanoparticles higher surface to volume ratio to achieve better oxidation and evaporation. The combustions attributes are of the nano additive tamarind seed biodiesel are better when compared with the sole tamarind seed biodiesel. Therefore, nano particles can be considered to be a good combustion catalyst as they contribute higher energy density, lesser engine emissions and enhanced combustion characteristics (V. Dhana Raju et al. 2018). The nano-additive produced from various metals has the major significance on the fuel properties, performance and combustion attributes. The Al_2O_3 nano additive has nominated as the best nano-additive as it exhibits smallest water droplet size, highest DTGmax and its consistency in increasing the torque and reducing the BSFC, brake specific NOx (BSNOx), BSCO compared to other nano-additives (A.K. Hasannuddin et al. 2018). The nano particles prepared from advanced nano technology had ensured the improved thermal properties of the nano additive blended fuels as they provides larges surface area to volume ratio (Ang F. Chen et al. 2018). Application of with novel nano additive to realize the full potential usage of locally available of bio-waste like dairy scum is highly distinct for the researchers. From the literature, it is observed that around 200-350 kg of waste scum is available from an industry which process 5 lakh liters of milk per day. It could be very beneficial for the dairy industry to manage the waste scum disposal. Conversion of this waste scum into fuel would give the extra benefits to the industry (Manjunath Channappagoudra et al. 2019). The nano-diesel-biodiesel fuel blend could contribute the better performance and reduced fuel consumption and exhaust emissions (HC & CO emissions) than the petro-diesel run diesel engines (M. Ghanbari et al. 2017). The performance of the diesel run with nano-additive fuel blends has shown the better performance and lowered emissions. However, in future the influence of CuO and Al_2O_3 nanoparticle size on the performance of the diesel engine can be studied. In addition, effect of nanoparticles on droplet spectrum by atomization of fuel and erosion effects of metal nanoparticles on engine and exhaust system could be studied for long time operation (Soner Gumus et al. 2016).

In this aspect, a new approach of developing and utilization of dairy scum oil biodiesel will play an imperative role in the reduction of conventional energy consumption and their environmental pollution. To realize the full potential use of dairy scum biodiesel in engine, some modifications in the base fuel may give the feasible solution for proper utilization of biodiesel in the IC engine. In this vision, the base B20 fuel blend is reformulated by adding nanoparticles in it to enhance the engine performance. From the experimental results, it is observed that the copper oxide nanoparticles (CuO-75 ppm) added 20% biodiesel blend has proven the better performance, combustion and emission characteristics when compared to sole 20% biodiesel blend (Manjunath Channappagoudra et al. 2018). The application of ZnO nanoparticles in biodiesel (Calophyllum Inophyllum Methly Ester) has shown the improved thermal efficiency and lower HC and CO emissions than the sole biodiesel. It could be due to catalytic effect of nanoparticle and micro explosion of water molecules present in the fuel. The exhaust gas treatment of the CI engine can be done by two methods namely using exhaust gas treatment devices like catalytic converter, diesel particulate filter and usage of fuel additives. Form the literature, it is observed that application nano additive and water emulsified fuels have show the significance improvement in the diesel engine performance (B. Ashok et al. 2017). The calorific value and cetane number of diesel and biodiesl fuel. Form the studies; it is evident that naoparticles addition into the fuel would increase the combustion of fuel by providing better heat transfer, catalytic activity, air-fuel mixing rate. However, increase in the dosing level of nanoparticles, there would be increased thermal efficiency. The B20+Mn2O3 and B20+Co3O4 nano-additives have shown the improved performance, reduced BSFC and CO emissions when compared to sole B20 fuel blend (Mina Mehregan and Mohammad Moghiman. 2018). Addition of zinc oxide and titanium dioxide nanoparticles in Calophyllum inophyllum biodiesel has revealed the improved thermal efficiency, combustion characteristics (cylinder pressure and heat release rate) and reduced HC, CO and smoke emission when compared to conventional diesel and pure Calophyllum inophyllum biodiesel under various engine loads. Finally, it can be observed that the doping of nano particles with biodiesel has a very good effect on performance characteristics with notable improvement in performances and minimum emissions (K. Nanthagopal et al. 2017). An earnest attempt towards conversion and exploitation of locally available bio-waste as alternative fuels for the internal combustion engine is highly distinct nowadays.

To realize the full potential usage of the bio-fuels a proper and minor modifications in the existing diesel engine is most invited. The study revealed that modified engine (IOP: 230 bar, IT: 26° bTDC, CR: 18, NH: 5 holes, Piston: TPBG (Toroidal piston bowl geometry) & RTPBG (Re-entrant toroidal piston bowl geometry)) has shown the better performance, combustion and emission characteristics than the existing baseline engine (IOP: 210 bar, IT: 23° bTDC, CR: 17.5

and NH: 3 holes, Piston: HPBG (Hemispherical piston bowl geometry)). Therefore modified engine with toroidal and re-entrant toriodal piston bowl geometry would contribute the improved performance for the diesel engine (Manjunath Channappagoudra et al. 2019; Manjunath Channappagoudra et al. 2018; Manjunath N. Channappagoudra et al. 2018). Due to enhanced properties of the nano-additive blended biodiesels have huge potential in the application of the diesel engine. From the literature, it is observed that many researchers are studied the effect of nano-additive on existing baseline diesel (un-modified) engine for different biodiesels and nanoparticles. Very rare works reported the effect of nano-particles on modified diesel engine run with biodiesel. This is the unique work reporting the effect of both modified fuel (B20-Al_2O_3-75 ppm fuel) and modified engine (IOP: 230 bar, IT: 26° bTDC, CR: 18, NH: 5 holes, Piston: RTPBG (Re-entrant toroidal piston bowl geometry)) on the performance, combustion and emission characteristics of the diesel engine run with waste dairy scum biodiesel.

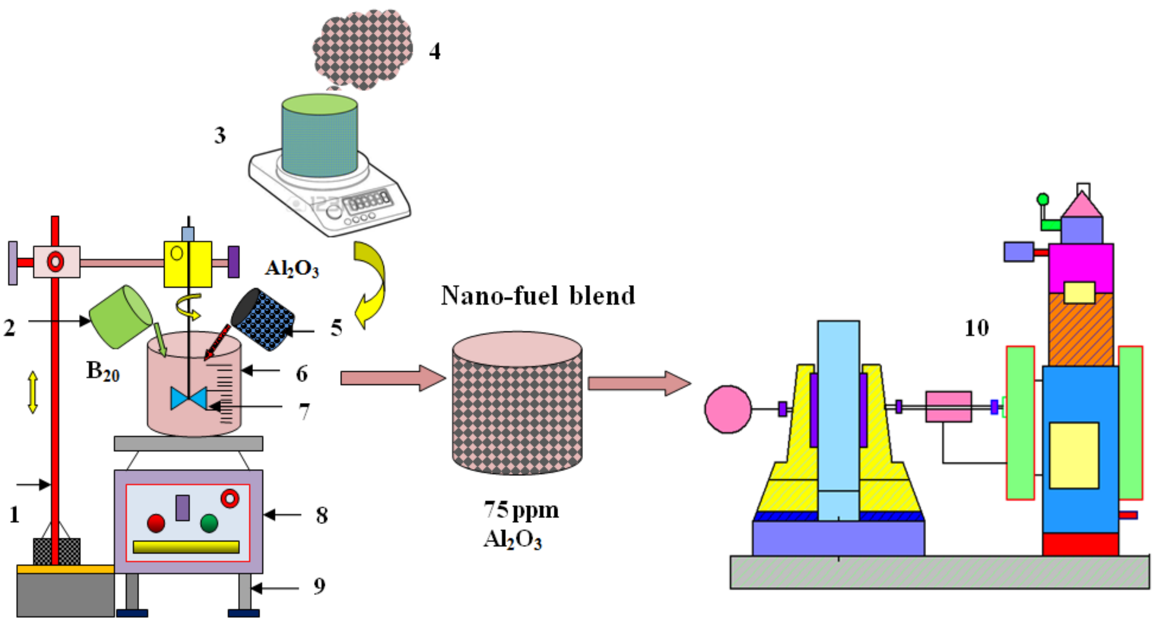
2. Materials and methodology

In the first step of study, 20% dairy scum biodiesel is considered as fuel and aluminum oxide (Al_2O_3) is considered as the nano-additive to evaluate the engine performance. In second step engine modifies with optimized engine parameters. Finally, in third step experimental results of (performance, combustion and emission characteristics) the both modified fuel and engine are compared with the existing baseline engine. The work matrix of the present study is presented in Table 1.

Table 1 Work matrix

Fuel and Nano-additive Selection	Engine Modifications	Experimental Investigation Parameters
Step-1: 1) Dairy scum biodiesel (B20) 2) Aluminum oxide (Al_2O_3)	**Step-2:** 1) IOP: 230 bar 2) IT: 29° bTDC 3) CR: 18 4) Nozzle: 5 holes 5) Piston: RTPBG	**Step-3:** 1) Performance 2) Combustion 3) Emission

In the current study, 75 ppm (0.075 gm) of Al_2O_3 nanoparticles particles are added to one liter of 20% diary scum biodiesel and nano particles are dispersed well with biodiesel blend using ultrasonicator and mechanical stirrer. To control the sedimentation of nano particles CTAB (Cetyl Trimethyl Ammonium Bromide) surfactant is employed to provide the negative charge to the particles to thus sedimentation of particle is avoided. To avoid the sedimentation of the nano particles, the fuel blends are shaken well before conducting the experimentation. The schematic view of the nano additive fuel blend preparation and utilization is demonstrated in Figure 1. The schematic view of the nano particles and fuel blend reactions is shown in the Figure 2.



1) Stirrer stand, 2) B20 container, 3) Electronic weighing machine, 4) Al_2O_3 nanoparticles, 5) CTAB surfactant+Al_2O_3 nanoparticles container, 6) Nano-fuel container, 7) Mechanical stirrer, 8) Ultrasonicator, 9) Ultrasonicator stand, 10) Photographic view of the engine.

Figure 1. Ultrasonicator and Mechanical stirrer for preparation of nano fuel blends.

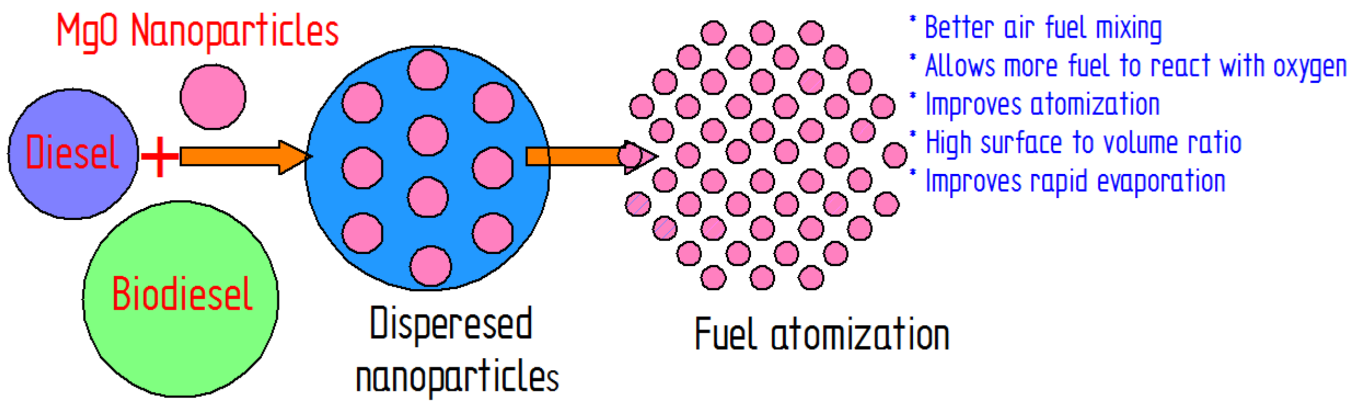


Figure 2.Atomization of nanoparticles dispersed test fuel.

2.1 Properties of nano additive fuel blends and engine modifications

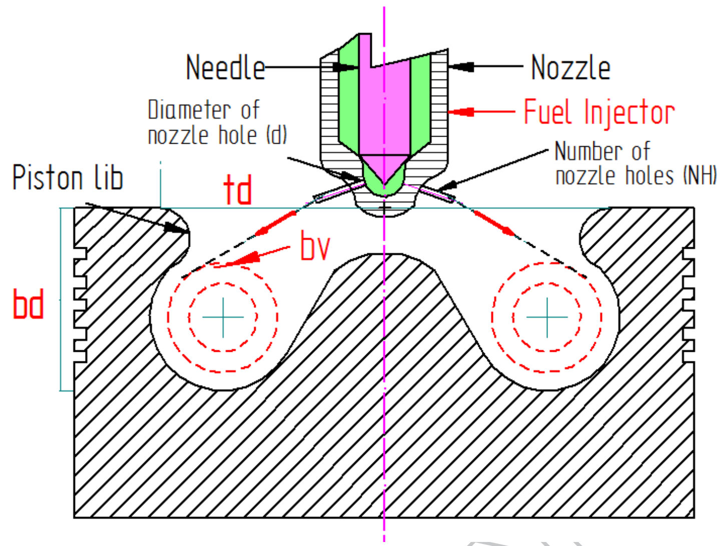
The properties of the diesel, biodiesel blends and nano additive fuel blends are determined as pert ASTM-6751 standards (Manjunath channappagoudra et al. 2018; Manjunath Channappagoudra et al. 2019; Manjunath Channappagoudra et al. 2018). Properties of the biodiesel and nano additive blends are shown in Table 2. Hydrometer is used to determine the density of biodiesel at 30ºC. Pensky-Martens closed-cup was used to check the flash and fire point of the fuel blends. Bomb calorimeter was used to determine the heating value of the test fuels. Redwood Viscometer was employed to determine the viscosity of the all test fuels.

Table 2 Properties test fuel blends.

Properties	Methods IS 1448	Diesel	B20	B20+ Al_2O_3-75
Density (kg/m^3)	P:16	830	840	840.35
Viscosity at 40°C (cSt)	P:25	2.9	2.98	3.001
Calorific value (kJ/kg)	P:69	43000	40890	41016
Flash Point (ºC)	P:69	50	58	55

After characterization of the fuel blends, the experiments are conducted on both baseline and modified engine (The specifications of the baseline and modified engines are given in the Table 3). The process of the swirl formation in the re-entrant toroidal combustion chamber is depicted in the Figure 3. The schematic and photographic views of the employed pistons are presented in

Figure 4 (a) and (b). At the end, experimental results assessed and compared with base sol B20 fuel blend and Petro-diesel.

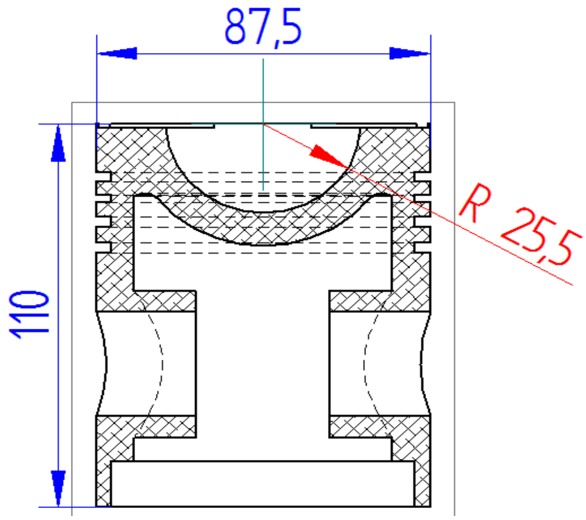


Note- bv: bowl volume, td: throat diameter, bd: bowl depth.

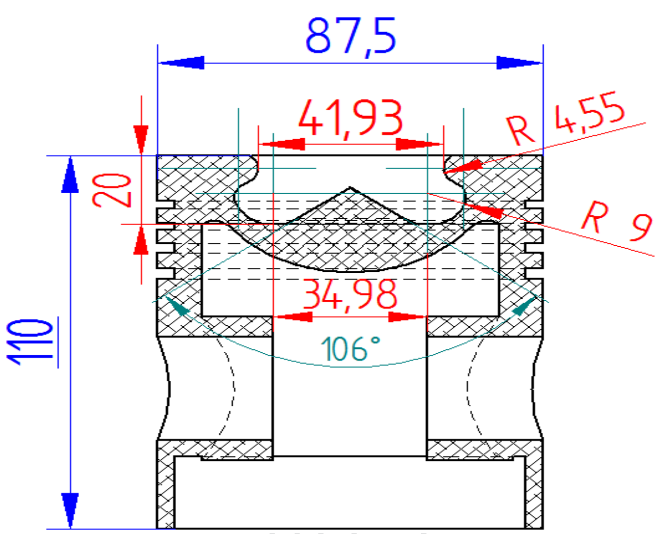
Figure 3. Schematic view of air motion inside the cylinder.

Table 3 Specifications of employed piston and fuel injectors.

Piston			Nozzle		
Particulars	**Standard**	**Modified**	**Particulars**	**Standard**	**Modified**
Name	HPBG	RTPBG	Number of hole	3	5
Bowl Volume (mm^3)	34727.95	34727.44	Part name	DLL110S639	DLLA142S1033
Throat diameter (mm)	51	51	Hole diameter (mm)	0.280	0.240
Bowl depth (mm)	25.5	17.15	Area (mm^2)	0.0616	0.0452
Piston diameter (mm)	87.5	87.5	Spray angle (θ°)	110	142



Hemispherical piston bowl geometry (HPBG)



Re-entrant toriodal piston bowl geometry (RTPBG).

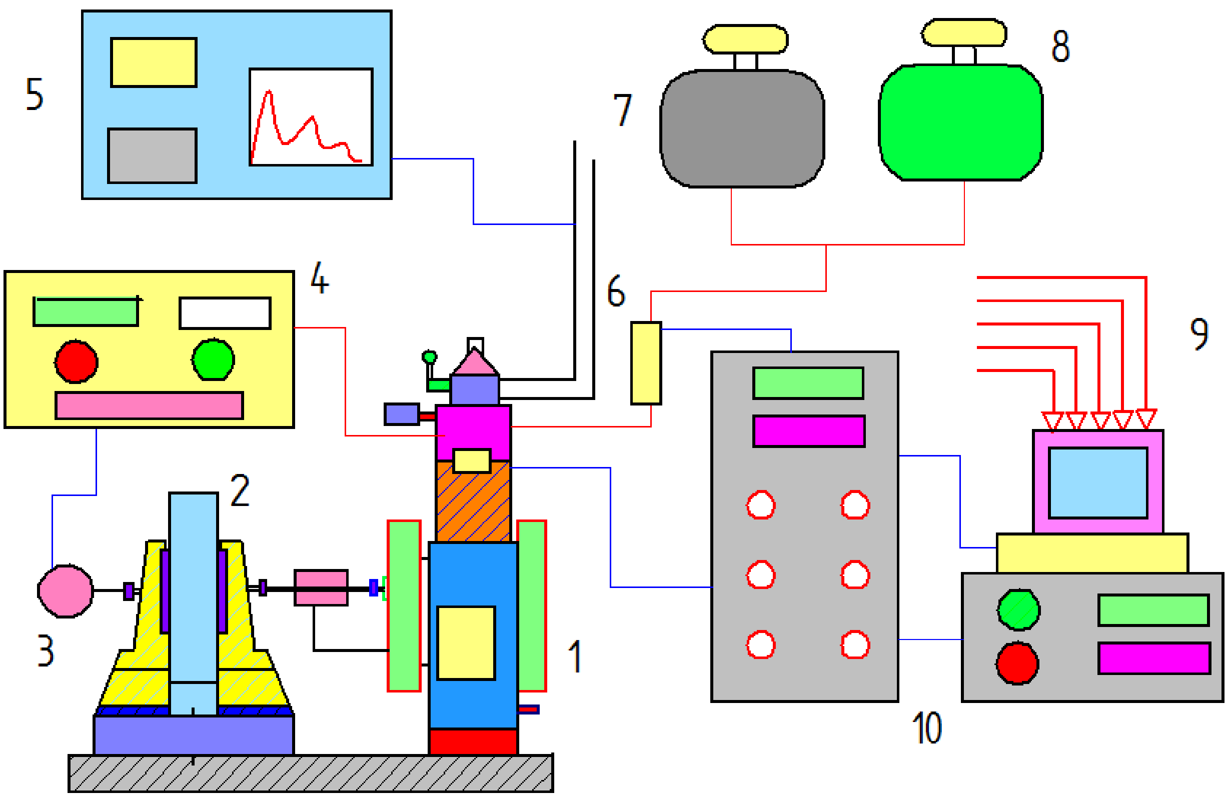
Figure 4 (a)

Figure 4 (b)

Figure 4. (a) Schematic and pictorial views **(b)** Fabricated dummy and real pistons.

2.2 Experimental test setup

The schematic and pictorial view of the experimental setup is depicted in Figure 5. The tests were conducted on Kirloskar (TV1) 4 stroke, VCR (variable compression ratio) diesel engine of 3.5 kW power. Eddy current dynamometer with load cell is used to vary the loads in steps of 20, 40, 60, 80 and 100%. Engine is operated at constant speed of 1500 rpm throughout the experiments. The detailed technical specifications of the engine are given in Table 4. The various flow meters are used to measure the fuel flow rate, water flow arte and air flow rate. The K type thermocouples are used to determine the various temperatures in the engine. The combustion parameters like P-θ, HRR, CHRR, ID, CD and PRR are evaluated with the help of "Engine soft LV" software with Piezosensor and crank angle sensors. Airrex Automotive Emission Analyzer HG-540 (Specification of the gas analyzer is given in **Table 5**) was used to determine the exhaust emissions (HC, CO, and NOx).



1: Engine, 2: Dynamometer, 3: Encoder, 4: Control panel, 5: Exhuast gas analyzer, 6: Fuel burette, 7: Diesel tank, 8: Biodiesel tank, 9:Temperature signals,10: Data acquisition system

Figure 5. Schematic view of the engine test setup.

Table 4 Engine specifications.

Parameters	Specifications
Type	TV1 (Kirloskar made)
Cubic capacity	661 cc
Bore and stroke length	87.5 mm X 110 mm
Injector opening pressure	210 bar
Rated power	3.5 kW at 1500 rpm
Injection timing	23ºbTDC (diesel)
No. of cylinder/stroke	One/Four
Cooling	water
Compression ratio	17.5
Dynamometer	Eddy current
Software used	Engine soft

Table 5 Specifications of exhaust gas analyzer.

HG-540	**Specifications**			
Measuring Range	HC	0-10000 ppm	CO	0.000-9.999%
Resolution		1 ppm		0.001 %
Measuring Range	CO_2	0-20 %	O_2	0-25 %
Resolution		0.01%		0.01 %
Measuring Range	NOx	0-5000 ppm	λ / AFR	0.500-3.000 /7.00-29.40
Resolution		1 ppm		0.01 / 0.01 %
Measuring Range	RPM (2-4 Stroke)	0-9999 rpm		
Resolution		1 ppm		
Repeatability	Less than ± 2% FS			
Response Time	Within 10 seconds (more than 90%)			
Warming Up	About 5-10 minutes			
Flow rate	2-4 liter/minute			
Power Supply	AC 90-260V, 50/60Hz with 10m length power cord (option: 0.3A DC12V)			
Operating Temperature	0° C-40° (Ambient) / Gas temperature: up to 400° C			
Dimension	270 (W) X 340 (D) X 165 (H) mm			
Weight	About 5 kg (Net), 8 kg (Gross)			
Print Type	Built-in 24 column printer (Dot Matrix / Thermal)			
Accessories	Gas sampling probe, probe hose, spare fuse, leak test cap, operation manual, and RS232 cable.			

3. RESULTS AND DISCUSSION

In the present study effect of Al_2O_3 nano-additive (75 ppm) on the performance of diesel engine is examined and experimental results are compared with the petro-diesel.

The effect of Al_2O_3 nano additive on baseline and modified engine is represented in the Figure 6. The baseline engine operation (BE-Diesel) with diesel has exposed the higher BTE (31.32%) when compared to baseline engine operation with B20 (BE-B20) fuel blend (29.93%). This higher BTE with diesel might be accredited to better combustion of diesel as it has higher heating value and lower viscosity leads to higher BTE. The modified engine (IOP:230 bar, IT:26° bTDC, CR:18, NH:5 holes, CC:HPBG) has shown the highest BTE of 33.01% when compared to baseline engine (IOP:210 bar, IT:23° bTDC, CR:17.5, NH:3 holes, CC:HPBG) BTE of 31.72% when both operated with optimized Al_2O_3-75 ppm nano fuel blend. This could be attributed to better fuel atomization, elevated cylinder temperature, rapid fuel oxidation and evaporation of fuel mixture in the modified engine run with nano fuel blends leads to better combustion. In addition, the modified engine with re-rentrant torodial piston bowl geometry (RTPBG) has contributed the power fuel swirl and squish during diffusion combustion phase leads to better combustion efficiency. Therefore, RTPBG (which has larger spray volumes) with modified engine and nano additive application (which provides large surface to volume ratio) exploit the complete oxygen which available in the combustion cavity hence cause better chemical reaction, fuel evaporation and combustion. At maximum load, about 9.33% of increased BTE is observed with the modified engine when compared to baseline run with optimized Al_2O_3-75 ppm nano fuel

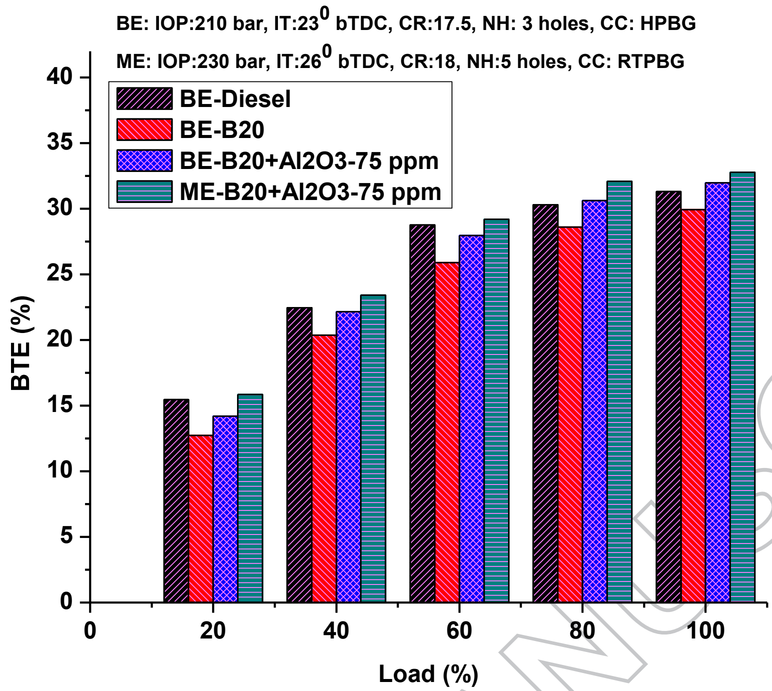


Figure 6.Brake thermal efficiency versus brake power.

Figure 7 represents the deviation of BSFC with brake power. The graph revealed that the B20 fuel blend has exposed the highest BSFC of 0.320 kg/kW.hr when compared to the petroleum diesel of 0.290 kg/kW.hr. This might be due to inferior heating value and higher density of B20 fuel results in higher fuel consumption. From the experimental investigation, it is cleared that the modified operated with Al_2O_3-75 ppm nano fuel blend has revealed the least BSFC of 0.267 kg/kW.hr when compared to baseline engine BSFC of 0.0.290 kg/kW.hr run with Al_2O_3-75 ppm. The fast fuel-air mixing and heat liberation which is caused by the enhanced swirl and squish of the modified engine might be the reason for the lower BSFC with modified engine when compared to the baseline engine. In addition, the higher surface activity of the nano additive would also cause the better combustion by providing large surface for the chemical reaction during the combustion phase. Hence, consume the less fuel than the sole B20 fuel blend run with baseline mode. On whole, the combined effect of modified engine and nano fuel addition in the base fuel has experienced the lower BSFC than the baseline engine run with base fuel. At full load, about16.56% of BSFC is lowered with the modified engine when compared to baseline engine run optimized Al_2O_3 nano fuel blend.

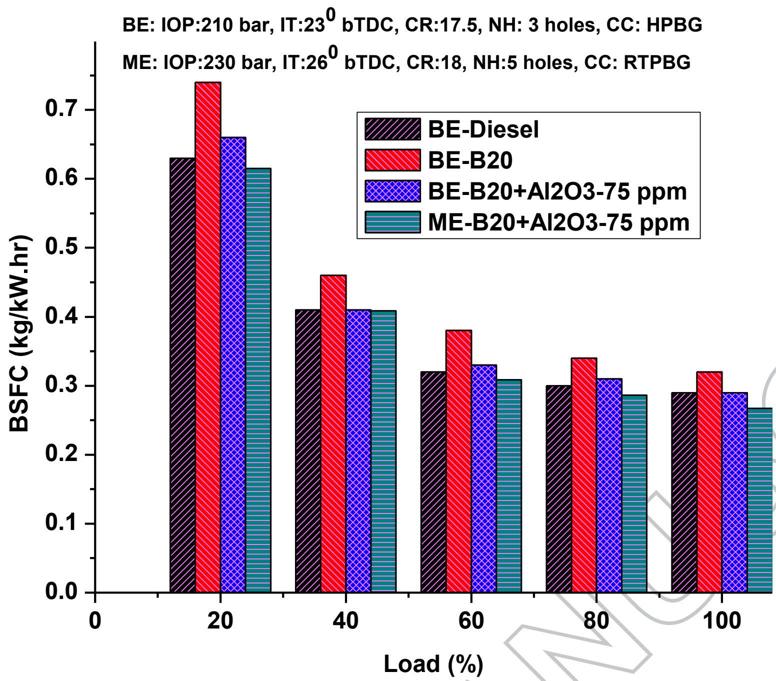


Figure 7.Brake specific fuel consumption versus brake power.

Figure 8 reveals the dissimilarity of HC emission with BP. The petro-diesel has resulted the maximum HC emission of 45 ppm when compared to B20 fuel blend of 40 ppm. The lesser oxygen content in the conventional diesel might contribute the incomplete combustion thus leads to increased HC emission than biodiesel blends. Whereas, more oxygen presence the bio-fuel blends intimate the clean and perfect combustion of charge hence results in better oxidation of hydrocarbons and enhanced combustion thereby decreases the HC emissions for baseline engine operation. From the experimental results, for all load ranges it is observed that the modified engine (ME-B20+Al_2O_3-75 ppm) has shown least HC emission of 31 ppm when compared to baseline engine (BE-B20+Al_2O_3-75 ppm) HC of 34 ppm operated with optimized Al_2O_3-75 ppm. The least HC emission with the modified engine might be due to superior fuel atomization, earlier evaporation, and augmented cylinder temperature lead to enhanced burning process. At 100% load, modified engine with re-entrant toroidal piston (RTPBG) has revealed the lowest HC emission than the baseline engine hemispherical piston bowl geometry (HPBG). It could be attributed to better combustion of fuel which is caused by combined effect of modified engine and naoparticle addition. At full load condition, about 22.5% of HC emission is reduced with modified engine when compared to baseline engine run with optimized Al_2O_3 nano additive fuel blend.

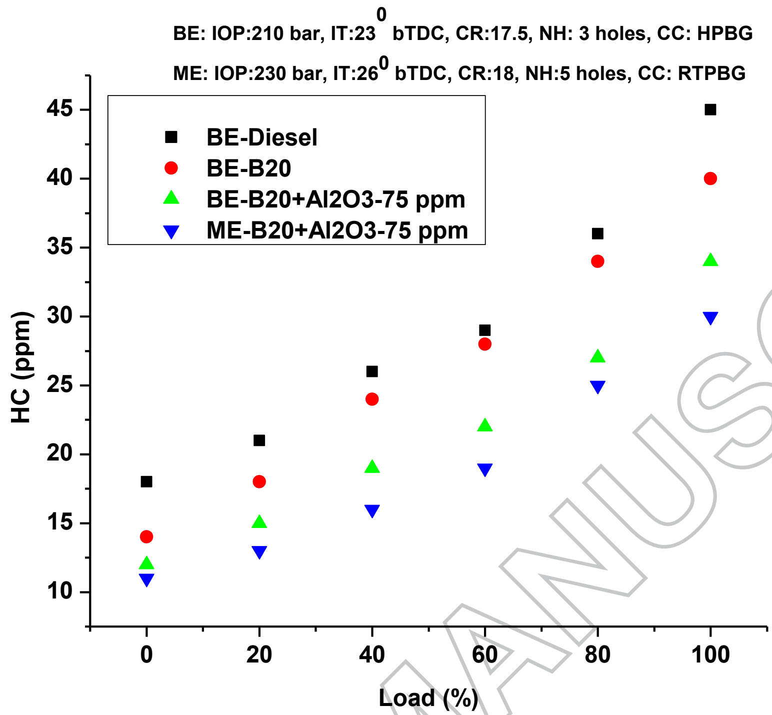


Figure 8.HC emission versus brake power.

The CO emission variation with BP is shown in the Figure 9. At 100% load, the diesel fuel blend has shown the highest CO emission of 0.089% when compared to B20 fuel blend CO emission of 0.076%. Because of higher oxygen concentration in the B20 fuel blend than the diesel, cause in better combustion thereby B20 fuel blend results in poorer CO emission. However, baseline engine has shown the more CO emission than the modified engine for entire load ranges. This could be accredited to the ineffective amalgamation of air and fuel particles due to stumpy turbulence, large fuel droplets from injectors resulting from poor atomization, long penetrations of the bulky fuel droplets within the combustion cavity ensuing in formation of locally fuel-rich zones. Whereas, the modified engine has shown the least CO emission of 0.0602% when compared to baseline engine CO of 0.068%, when both engines operated with Al_2O_3-75 ppm fuel blend. This might be due to advanced air motion into the cylinder and surface area to volume ratio and catalytic activity of nanoparticles liberating the more heat, hence augmented the burning temperature. This increased combustion temperature would enhance the oxidation and combustion process. As the oxidation process is improved by modified engine and nano-additives, cause in the lower HC and CO formation during combustion. At 100% load, about 20.78% of HC emission is reduced with the modified engine run with Al_2O_3-75 ppm than the baseline engine run with sole B20 fuel blend.

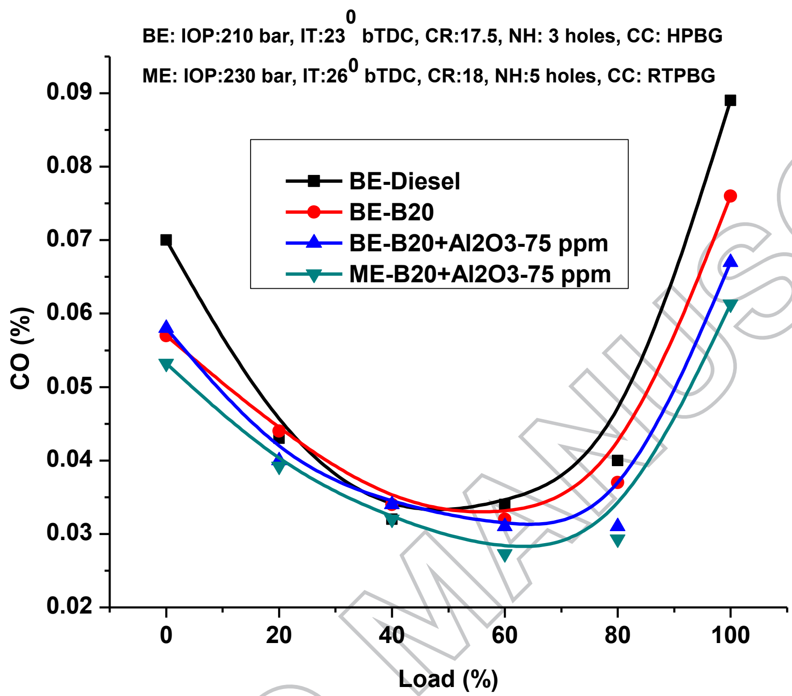


Figure 9.CO emission versus brake power.

Figure 10 illustrates the variation of NOx emission with brake power. Due to attendance of the additional oxygen existence in the B20 fuel blend than petro-diesel, the B20 blend caused the higher HRR and cylinder temperature consequences in higher NOx formation. At full load, the baseline engine operated with B20 fuel blend has shown the higher NOx emission of (978 ppm) when compared to fossil diesel fuel (961 ppm). However the modified engine has shown the highest NOx emission of 1173 ppm when compared to baseline engine of 1087 ppm when both the engines operated with optimized Al_2O_3 nano fuel blend. This might be due to improved air motion and inherent oxygen biodiesel with RTPBG and better surface activity provided by the nano-additive build up the more heat liberation and heat transfers to the burned and unburned portions hence causing in augmented combustion temperature. Therefore this higher cylinder temperature causes the greater NOx emission formation in the modified engine when compared to baseline engine run with Al_2O_3-75 ppm at full load condition.

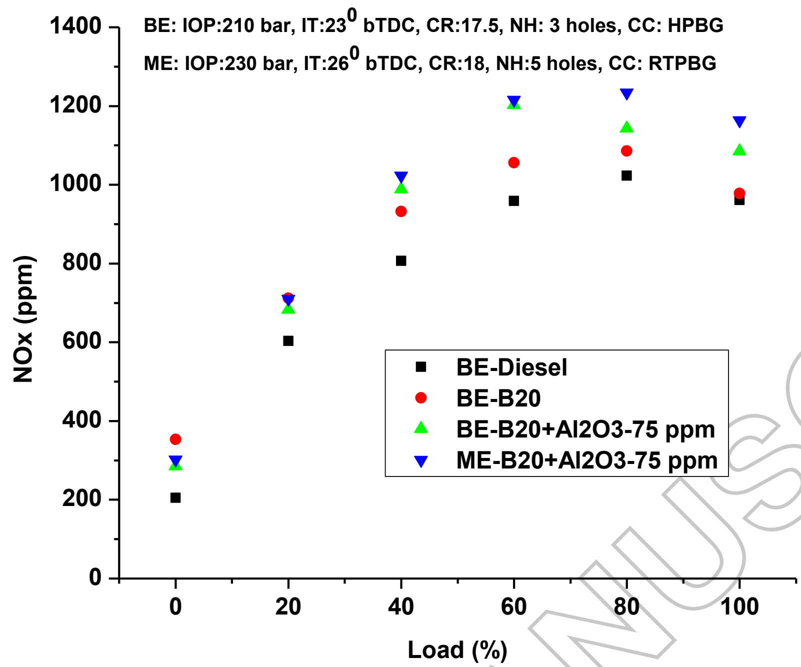


Figure 10.NOx emission versus brake power.

The variation of cylinder pressure against crank angle at full load is presented in Figure 11. The lowest cylinder pressure is observed with sole B20 fuel blend (52.18 bar) than the diesel fuel (53.83 bar) for baseline engine operation. However, modified engine (with RTPBG piston) has shown the highest cylinder pressure of 56.17 bar than the baseline engine (with HPBG piston) of 52.33 bar when the both engines operate with Al_2O_3-75 ppm fuel blend. Modified engine and nanoparticles blended fuel resulted in highest in-cylinder pressure than the baseline engine run with sole B20 fuel blend. This could be ascribed to enhanced squish-swirl interaction with re-entrant design and faster chemical reaction and oxidation consequences absolute burning in modified engine with Al_2O_3-75 ppm fuel blend cause the improved combustion efficiency. At 100% load, about 7.10% of increased cylinder pressure is monitored with the modified engine when compared to baseline engine run with Al_2O_3 nano additive fuel blend.

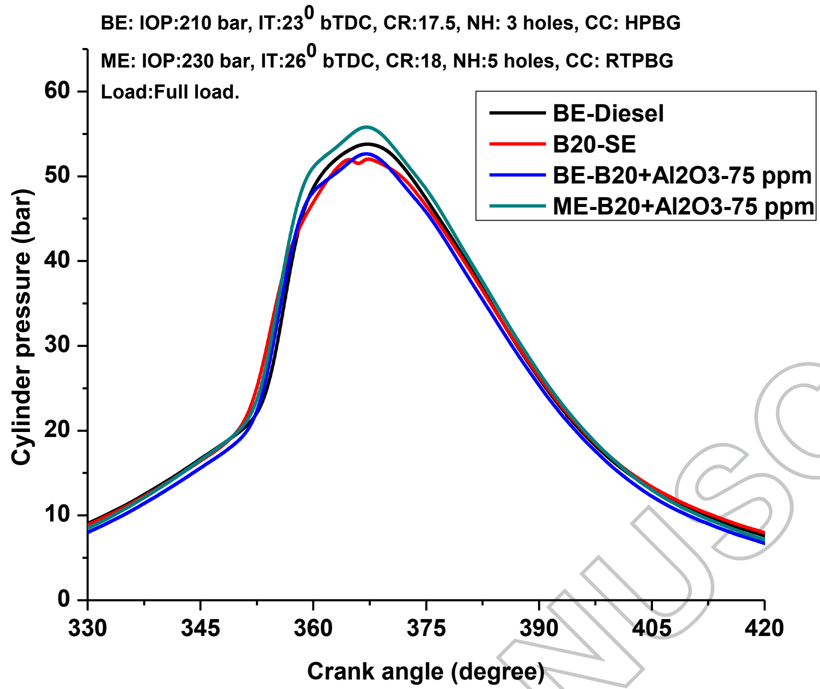


Figure 11.Cylinder pressure versus crank angle at full load.

Figure 12 shows the rate of HRR silhouettes with crank angle. At maximum load, the diesel has shown the greater HRR of 65.43 J/°CA when compared to the sole B20 operation of 57.14 J/°CA for baseline engine mode. The higher HRR with diesel might ascribed to higher heating value of fuel leads better combustion hence results in higher HRR tan the B20 fuel blend. From the graph at full load, it is also noticed that modified engine has highest HRR of 66.11 J/°CA when compared to baseline engine HRR of 62.05 J/°CA when the both engines operated with optimum MgO-75 ppm nano fuel blend. This improvement with modified engine with nano additive fuels might be accredited to better fuel atomization, enhanced fuel-air mixing rate and rapid evaporation of charge during premixed and diffusion combustion phase. Because the combination of these two contribute the enhanced oxidation, chemical reaction, better atomization, better secondary atomization (by nanoparticles) and better mixing of air-fuel in the combustion cavity during the controlled and uncontrolled combustion phase hence cause the improved combustion. At maximum load condition, for Al_2O_3-75 ppm operation, about 13.56% of enhanced HRR is noticed with the modified engine when compared to baseline engine.

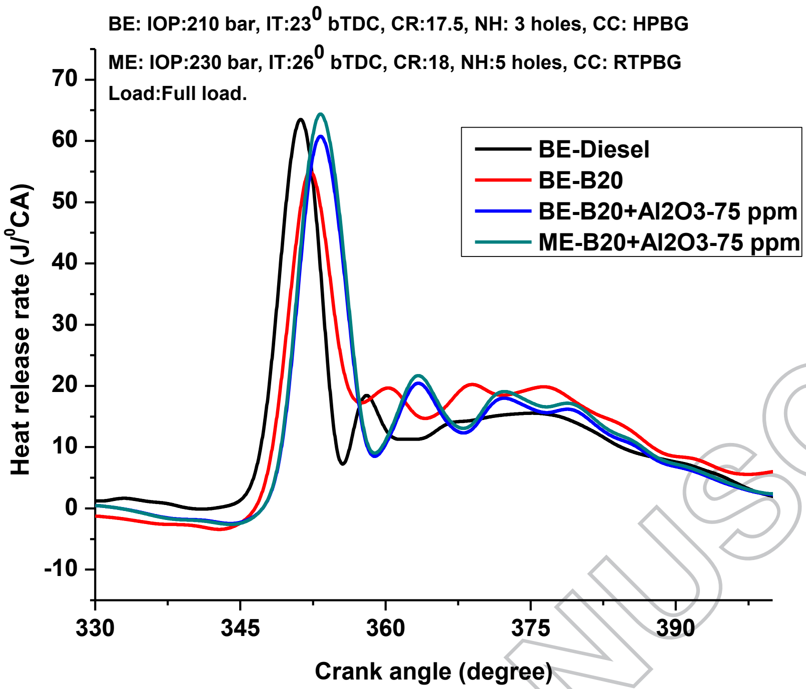


Figure 12. Heat release rate versus crank angle at full load.

4. CONCLUSION

The present study examined the effect of aluminum oxide on the performance of both modified and un-modified diesel engine. From the experimental learn the following conclusions are drawn:

1) At maximum load, about 9.33% of BTE and 13.56% of heat release rate is increased with modified engine operated with B20-Al_2O_3+75 ppm fuel blend when compared to baseline engine run with sole B20 fuel blend.
2) However, about 16.56 of BSFC, 22.5% of HC and 20.78% of CO emissions are reduced with modified engine run with B20-Al_2O_3+75 ppm nano additive fuel blend when compared to baseline engine run with sole B20 fuel blend.

On whole, modifications in existing diesel engine and modifications in the base fuels with addition of nano additive would contribute the better performance, emission and combustion attributes when compare to sole biodiesel operation in baseline engine.

Abbreviations

ASTM	American society for testing materials
BE	Baseline Engine
BE-Diesel	Baseline engine operated with diesel
BE-B20	Baseline engine operated with 20% biodiesel or DSOME-B20
BE-B20+ Al_2O_3-75 ppm	Baseline engine operated with 20% biodiesel blended with 75 ppm of MgO
BP	Brake power (kW)
BSFC	Brake specific fuel consumption (kg/kW.hr)
bTDC	before Top dead centre
BTE	Brake thermal efficiency (%)
B20	80% Pure diesel+20% Biodiesel
B20-BE	80% Pure diesel+20% Biodiesel operated Baseline Engine
B20+ Al_2O_3-75 ppm	80% diesel+20% biodiesel+75 ppm Magnesium Oxide nanoparicles
B20+Co3O4	20% Biodiesel +80% Diesel+ cobalt oxide nanoparticles
B20+Mn2O3	20% Biodiesel +80% Diesel+ Manganese oxide nanoparticles
CA	Crank angle (degree)
CO	Carbon monoxide (%)
CR	Compression ratio
DSOME	Dairy scum oil methyl ester (biodiesel)
HC	Hydrocarbons (ppm)
HPBG	Hemispherical piston bowl geometry
HRR	Heat release rate
IOP	Injector opening Pressure
IT	Injection timing
kW	killo Watt
ME	Modified engine
ME-B20+ Al_2O_3-75 ppm	Modified engine run on B20 fuel blended with 75 ppm nano additive
NH	Nozzle hole
NOx	Nitrogen oxide (ppm)
PBG	Piston bowl geometry
ppm	Parts per million
RTPBG	Re-entrant toroidal piston bowl geometry

References

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