Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2016, 8(3):246-257

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Investigation on aluminium oxide nano particles blended diesel fuel combustion, performance and emission characteristics of a diesel engine

N. Madhan Raj*[1], M. Gajendiran[1], K. Pitchandi[1] and N. Nallusamy[2]

[1]Department of Mechanical Engineering, Sri Venkateswara College of Engineering, Sriperumbudur – 602117, Tamil Nadu, India
[2]Department of Mechanical Engineering, SSN College of Engineering, OMR, Kalavakkam – 603110, Tamil Nadu, India

---

ABSTRACT

Diesel engine plays a vital role in power generation, transportation and industrial activities. The main advantages of the diesel engine over the gasoline spark ignition engine include its durability, reduced fuel consumption and lower emission of carbon monoxide and unburned hydrocarbon. Due to higher efficiency, diesel engines are of high interest in light duty vehicles. The objective of the present study is to investigate the effect of aluminium oxide nanoparticles blended diesel fuel combustion, performance and exhaust emission characteristics of a diesel engine. Experiments were conducted to determine engine performance, emissions and combustion characteristics in a single cylinder diesel engine using diesel fuel (DF) and diesel fuel blended aluminium oxide nanoparticles in mass fractions of 25ppm (DF+AONP25) and 50ppm (DF+AONP50), respectively with the help of a sonicator. After a series of experiments it was observed that 25ppm of aluminium oxide nanoparticles blended fuel exhibits a significant reduction in specific fuel consumption and hydrocarbon emissions at all operating loads compared to other cases. There is a considerable reduction in carbon monoxide and smoke emissions. Due to complete combustion NOx emissions increases. The results also showed a considerable enhancement in brake thermal efficiency due to the influence of aluminium oxide nanoparticles addition in diesel blend. As the dosage level of aluminium oxide nanoparticles increases to 50ppm the brake thermal efficiency, HC, CO and NOx emissions decreases considerably with respect to 25ppm of aluminium oxide nanoparticles blend. There is a noticeable increase in specific fuel consumption and smoke emissions of DF+ANOP50 with respect to DF+ANOP25.

Keywords: Aluminium oxide nanoparticles (AONP), Diesel, Ultrasonicator, Combustion, Performance, Emissions, Coefficient of variations (COV)

INTRODUCTION

Increasing liquid fuel prices and impending emission regulations have sharpened the automotive industries to focus on efficiency. Moreover the rapid depletion of fossil fuels due to widespread use has forced to search for some low emission and renewable sources. Emissions of diesel fueled vehicle have high concentration of NO_x and particulate matter. The mixture contain carbon particle that are exceptionally small in size, less than one micron. The environmental concern, emission from motor vehicle have become an impute begetter of air pollution. As fossil fuels are limited sources of energy, this increasing demand for energy has led to a search for alternative sources of energy that would be economically efficient, socially equitable, and environmentally sound. Conventional fuels have been found rather inadequate in improving emission characteristics which is the very first need of impeding emission regulation. Nanoparticles could decrease the emission parameter and can improve combustion efficiency by improving the ignition delay and fuel properties. Nanoparticles had the potential as the next generation fuel for lowering emission and combustion efficiency improvement.

Rolvin D'Silva et al. [1], conducted experiments on the addition of TiO_2 nanoparticles with diesel fuel in compression ignition engine. The addition of TiO_2 nanoparticles enhances higher carbon combustion activation, act as oxygen buffer and hence promotes complete combustion. Due to the complete combustion of fuel, emissions such as CO and HC are appreciably reduced.

Basha et al. [2], had investigated the effect of carbon nanotube (CNT) into diesel to achieve better performance and reduced emission .The experiment were conducted on single cylinder four stroke water-cooled DI diesel engine with an electrical loading device at constant speed of 1500 RPM using neat diesel and CNT blended diesel without any modification in engine. It was observed that magnitude of emission characteristics such as NO_x, CO, HC, EGT and smoke opacity is comparatively less compared to neat diesel.

Kao et al. [3], had investigated the combustion of aluminum nanofluid into diesel. An ultrasonicator was used to produce emulsified nano-aluminum liquid. It was observed using nano-aluminum diesel (AN+D) fuel had lowered the BSFC compared with diesel D fuel. The aluminum nanopowder additive mixed in D fuel causes a clear smoke reduction for engine speed less than 1800 RPM and NOx concentration was showing a decreasing trend. Selvaganapthy et al. [4], studied the role of Zinc oxide (ZnO) nanoparticles on the performance of single cylinder four stroke vertical water cooled diesel engine. The results showed that the thermal efficiency is 35.82% only at full load for diesel fuel (DF), whereas 36.8% and 37.35% was obtained for DF+ZnO (250 ppm) and DF+ZnO (500 ppm) respectively.

Mehta et al. [5], Investigated the burning characteristics, engine performance and emission parameters of a single-cylinder Compression Ignition engine using nano fuels which were formulated by sonicating nano particles of aluminum (Al) having 30-60nm, iron (Fe) 5-150 nm and boron (Bo) 80-100 nm in size in base diesel with 0.5wt% and 0.1wt% Span80 as a surfactant for stable suspension. At higher loads, the emission study showed a decline of 25–40% in CO (vol. %), along with a drop of 8% and 4% in hydrocarbon emissions for A1 and Fe nano fuels respectively. Due to elevated temperatures a hike of 5% and 3% was observed in NOx emission with A1 and Fe. Shafii et al. [6], had performed test on a four cylinder, compression ignition engine, operating at 2200 rpm. A water based Ferrofluid was added to diesel fuel to explore the effects on the engine exhaust emission. Results formulated on basis of load variation, which shows that adding 0.4% ferrofluid to diesel fuel decreased NOx emission by 9 to 15 ppm, adding 0.8% Ferrofluid to diesel fuel decreased NOx emission by 14 to 24 ppm.

Mozhi et al. [7], had investigated the performance, combustion and emission characteristics of a variable compression ratio engine using cerium oxide nanoparticles and carbon nanotubes as fuel-borne nanoparticles additives in diesterol (diesel–biodiesel–ethanol) blends. The Cerium Oxide nanoparticles were an oxygen donating catalyst which provides oxygen for the oxidation of carbon monoxide and absorbs oxygen for the reduction of nitrogen oxides. The activation energy of Cerium Oxide was to burn off carbon deposits and helps to prevent the deposition of non-polar compounds on the cylinder wall resulted in significant reduction of hydrocarbon and smoke emissions. Lenin et al. [8], performed the experiments on a single cylinder diesel engine for evaluation of diesel doped with metal additives MnO. Brake thermal efficiency was increased and the exhaust emission measurements for the fuel with manganese additive showed that CO is reduced by 37% due to higher carbon activation.

EXPERIMENTAL SECTION

2.1. Preparation of fuel blend

For the blending of aluminium oxide nanoparticles in diesel, taken a sample of diesel say 1litre and then 0.025g of aluminium oxide in the nanoparticles form is added to make the dosing level of 25 ppm. The dosing level of 25 ppm is 0.025 g/l, respectively. After the addition of aluminium oxide nanoparticles, it is shaken well and then it is poured into mechanical homogenizer apparatus where it is agitated for about 30 min in an ultrasonic vibrator making uniform dispersion. It should be shaken well before use, as excess of nanoparticles settle down on solution. Similar procedure carried out for 50ppm with 60 min agitations.

2.1.1. Properties of diesel blend samples
The properties of diesel were determined by standard methods like bomb calorimeter, redwood viscometer and open cup apparatus. Table 1 shows the properties of the fuel

Table 1 Properties of fuel

Properties	Diesel DF	DF+ANOP25	DF+ANOP50
Flash point (°C)	48	50	52
Fire point (°C)	52	54	56
Kinematic viscosity @40 °C ($x10^{-6}m^2/s$)	2.56	2.60	2.63
Calorific value (kJ/kg)	43500	43630	43783
Density (kg/m^3)	830	832	833

2.2. SEM of aluminium oxide nanoparticles

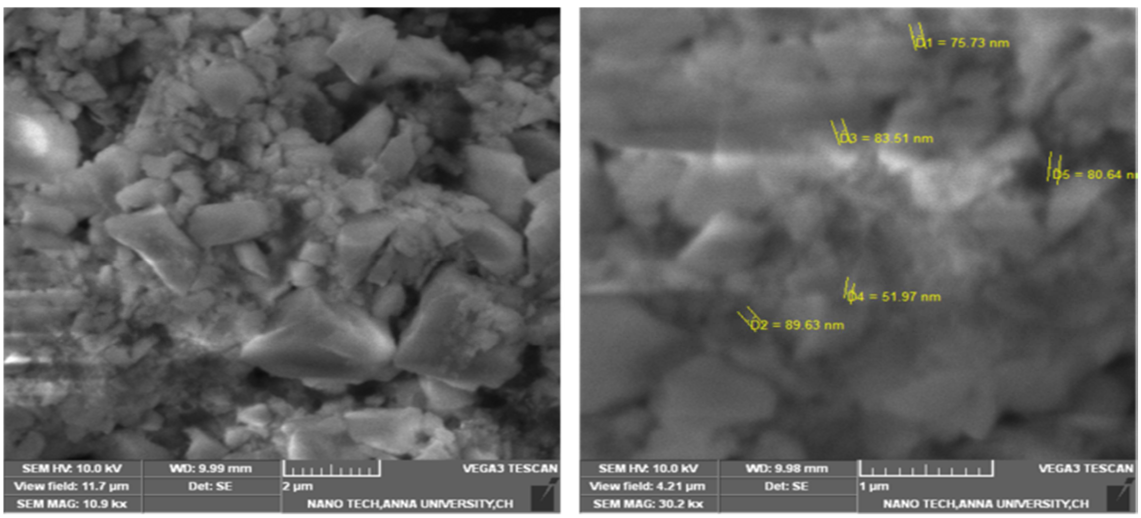

Figure 1 Structure of Nanoparticles

The size of the crystals is very important in nano materials to evaluate the mechanical and chemical properties. The SEM images show aluminium oxide nanoparticles with a particle size of less than 100 nm as shown in fig.1. Surface and morphological characterization of aluminium oxide nanoparticles was carried out using scanning electron microscopy. The mean size of aluminium oxide nanoparticles varies from 60 to 70 nm.

3. EXPERIMENTAL SETUP AND TEST PROCEDURE
Experiments were conducted on a Kirloskar, four stroke, single cylinder, air cooled diesel engine. The schematics of the experimental setup are shown in fig.2. The rated power of the engine was 4.4 kW and the engine was operated at a constant speed of 1500 rpm and a standard injection pressure of 200 bar. Specifications of the test engine were given in Table 2. The fuel flow rate was measured on a volume basis using a burette and a stop watch. Thermocouple and a digital display were used to note the exhaust gas temperature. The AVL415 smoke meter was used for measuring FSN of exhaust smoke. NO_x, HC and CO emissions were measured by AVL five gas analyzer. The inner cylinder pressure was measured with the help of combustion analyzer. The experiment was carried out with different blends of fuel. Readings were taken when the engine was operated at a constant speed of 1500 rpm for all loads.

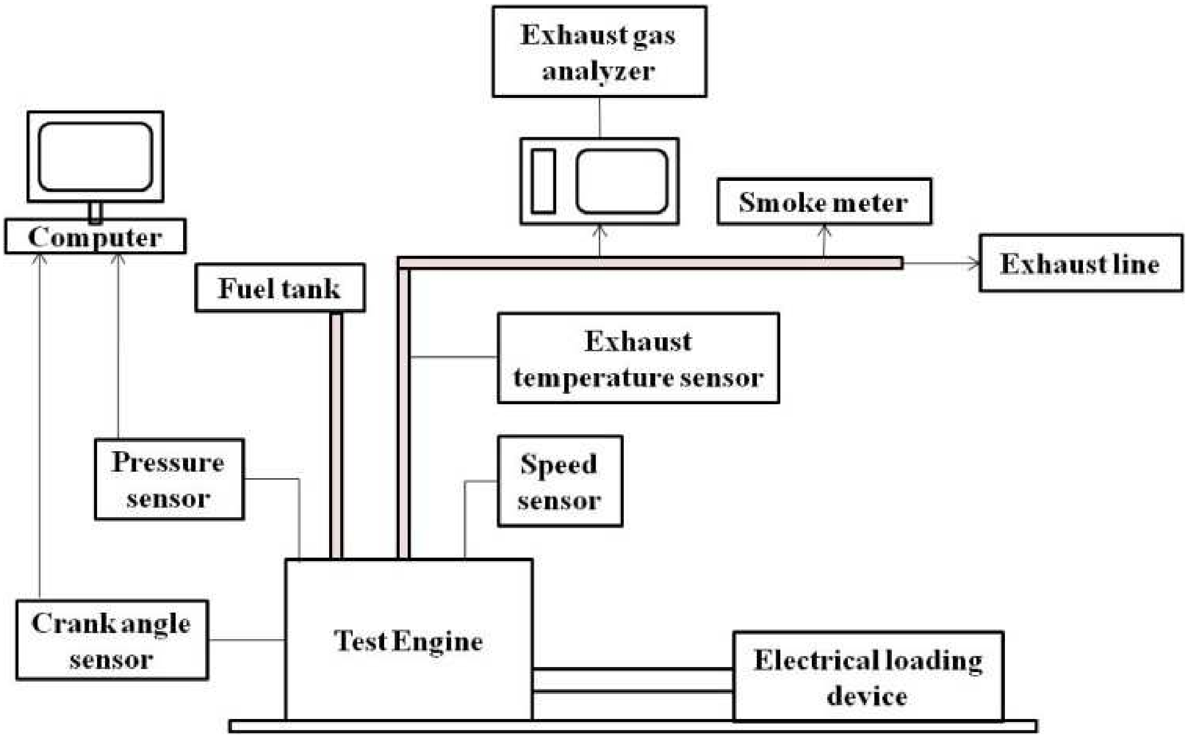

Figure 2 Experimental setup

Table 2 Engine Specification	
Type	Vertical, air cooled, four stroke single cylinder diesel engine
Make	Kirloskar
Number of cylinders	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Maximum power	4.4 kW
Dynamometer	Electrical
Speed	1500 rpm
Injection timing	23 deg CA(before TDC)
Injection pressure	200 bar

Parameters such as engine speed, fuel flow and emission characteristics such as NO_x, HC, CO and smoke were recorded. The performance of the engine was evaluated in terms of brake thermal efficiency and specific fuel consumption from the above parameters. The combustion characteristics such as cylinder pressure and heat release rate were noted for different fuels.

4. MEASUREMENT OF COEFFICIENT OF VARIATIONS

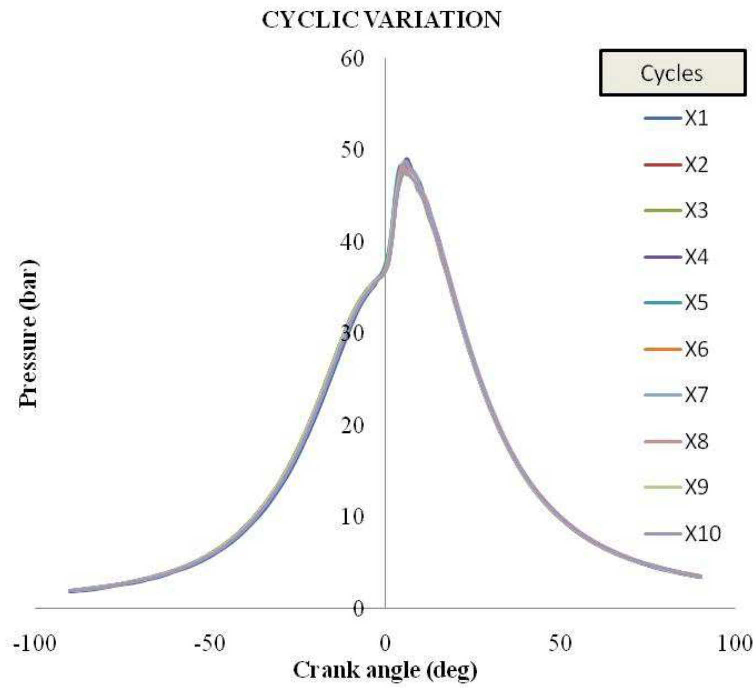

Figure 3 Cylinder pressure cyclic variations Vs Crank angle

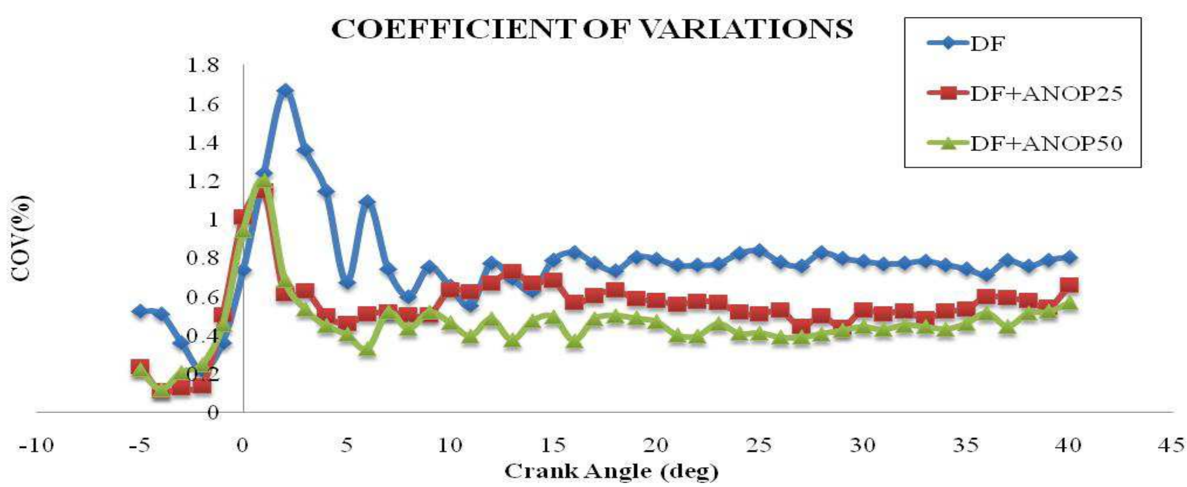

Figure 4 Coefficient of variations Vs Crank angle

Fig.3 shows ten consecutive readings of cylinder pressure with respect to the crank angle where x1 to x10 are ten consecutive engine cycles. Coefficient of variation measures the cyclic variation of the cylinder pressure with respect to the crank angle. The repeatability of the measured data is analyzed using coefficient of variation. Ten consecutive readings of cylinder pressure with respect to crank angle of diesel (DF) and aluminium oxide nanoparticles blended diesel (DF+ANOP25 and DF+ANOP50) fuels are measured. The coefficient of variation (COV(x)) is calculated using the following formula

$$COV(x) = \frac{\sigma}{\bar{x}} * 100\% \quad (1)$$

Where

Average, $\bar{X} = \sum_{i=1}^{n} x_i/n$ (2)

Standard deviation, $\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{X})^2}{n-1}}$ (3)

Fig.4 shows the coefficient of variations of the measured fuels from start of combustion to the end of injection period. It was found that maximum coefficient of variations for diesel, nanoparticles blended diesel of 25ppm and 50ppm fuels are 1.67%, 1.14% and 1.19%, respectively. The coefficient of variations of the measured fuels is well below the acceptable limits of 10% **[9]**. Hence the measured data are acceptable.

RESULTS AND DISCUSSION

In the present study, the performance, emission, and combustion characteristics of the engine fuelled with diesel (DF) and aluminium oxide nanoparticles blended diesel (DF+ANOP25 and DF+ANOP50) fuel blends were compared and discussed.

5.1. Engine performance parameters

5.1.1. Brake specific fuel consumption

The tests were performed for pure diesel (DF) and aluminium oxide nanoparticles blended diesel (DF+ANOP25 and DF+ANOP50) samples. Experimentally, it was observed that the fuel consumption increases when the load was increased for all operations of diesel and diesel blends. Fig.5 shows the variation of brake specific fuel consumption with respect to brake power for diesel and diesel blend of aluminium oxide nanoparticles. The brake specific fuel consumption of aluminium oxide nanoparticle blended diesel (DF+ANOP25) fuel is lower than that of diesel fuel (DF) for all loads. Aluminium oxide nanoparticles oxidize the carbon deposits in the engine cylinder leading to reduced fuel consumption. From the fig.5 it is observed that the brake specific fuel consumption values of neat diesel fuel and aluminium oxide nanoparticles blended diesel fuels are nearly same at moderate load, while DF+ANOP25 shows a considerable decrease of about 7% and DF+ANOP50 shows a considerable decrease of about 4% in comparison with the diesel fuel (DF) at all other loads. For DF+ANOP50, the increase in fuel consumption was more than that of DF+ANOP25 blend. This was due to the higher viscosity compared to DF+ANOP25 blend. Nanoparticle blended diesel were found to be improved with the increase in their calorific value due to presence of aluminium oxide nanoparticle which acts as oxygen buffer, thereby making the engine to consume less fuel compared to diesel fuel to overcome identical load.

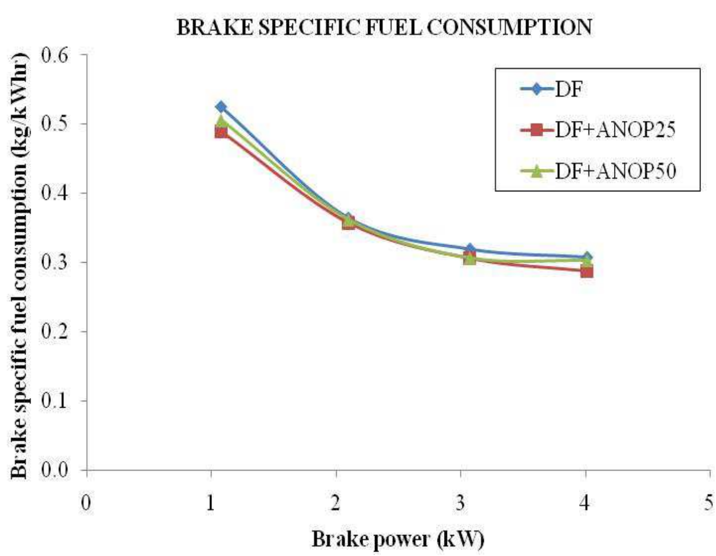

Figure 5 Brake specific fuel consumption Vs Brake power

5.1.2. Brake thermal efficiency

The Brake thermal efficiency is defined as the ratio of work output at the engine shaft to the energy supplied by fuel. It is a measure of the engine's ability to make efficient use of fuel. Fig.6 shows the variation of the brake thermal efficiency with respect to brake power. The results show that the brake thermal efficiency of the diesel engine is improved by the addition of aluminium oxide nanoparticles in the diesel fuel. The metal oxide nanoparticles present in the diesel blend encourage complete combustion, when compared to the sole diesel fuel. Aluminium oxide nanoparticles act as an oxygen buffer and thus improve the brake thermal efficiency. The aluminium oxide nanoparticle offers the secondary atomization immediate after the primary micro explosion phenomenon of diesel fuel. As the atomization takes place nanoparticle offer high surface area to volume ratio which leads to catalytic combustion resulting in an increased thermal efficiency. A maximum increase of 6% and 3% in the brake thermal efficiency was obtained from DF+ANOP25 and DF+ANOP50 with respect to diesel fuel (DF). As the dosage level of aluminium oxide nanoparticles increases the consumption of fuel also increases due to higher viscosity. As a result the brake thermal efficiency of DF+ANOP50 decreases with respect to DF+ANOP25.

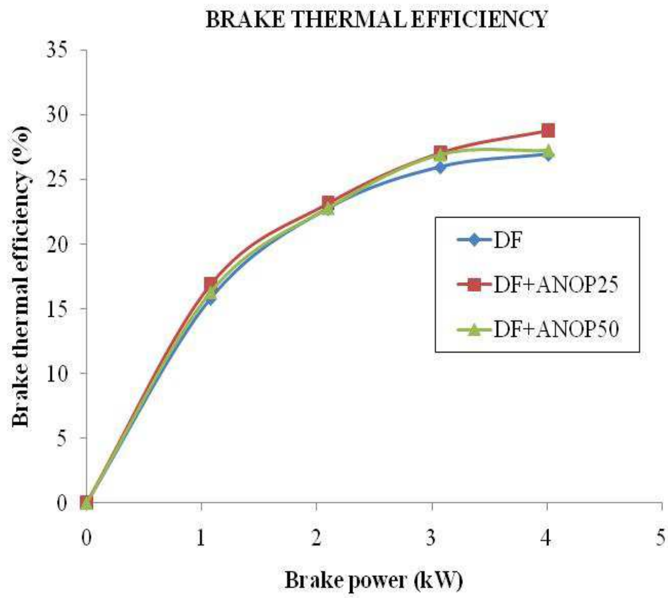

Figure 6 Brake thermal efficiency Vs Brake power

5.2. Emission parameters

5.2.1. Hydrocarbon

Fig.7 shows the variation of hydrocarbon emissions for 25 ppm and 50ppm level of aluminium oxide nanoparticles in diesel blend. Addition of aluminium oxide nanoparticles increases the level of oxygen content in the diesel blend. However, oxygen content of fuel is the main reason for HC emission reduction and complete combustion. From this fig.7, it is seen that as the load increases hydrocarbon emission also increases due to insufficient availability of oxygen. Hydrocarbon emission is found to be considerably reduced with the addition of the nanoparticles to diesel fuel. The hydrocarbon emission of diesel fuel decreased on addition of aluminium oxide nanoparticles of 25ppm and 50ppm by about 45% and 40%, especially at low load. DF+ANOP50 reduce the carbon combustion activation compared to DF+ANOP25. Hence HC emission increases on further addition of nanoparticles were obtained.

5.2.2. Carbon monoxide

Carbon monoxide highly relies upon the air-to-fuel proportions comparative to stoichiometric ratio. Fig.8 shows the influence of the aluminium oxide nanoparticles addition to diesel on carbon monoxide emissions. Nano metal oxide particles as an oxidation catalyst lead to higher carbon combustion activation and hence promote complete combustion. The nanoparticle blended fuels showed accelerated combustion due to the shortened ignition delay. Due to shorten of ignition delay, the degree of fuel–air mixing and uniform burning have enhanced. Hence, there was an appreciable reduction in carbon monoxide emissions for aluminium oxide blended diesel fuel. At higher load due to poor mixing of air and fuel mixture CO emission is increased. CO emissions are almost same for DF+ANOP25 and DF+ANOP50 fuels, except at 25% load condition. A maximum decrease of 50% and 40% in CO emission was obtained for DF+ANOP25 and DF+ANOP50 fuels with respect to diesel fuel (DF).

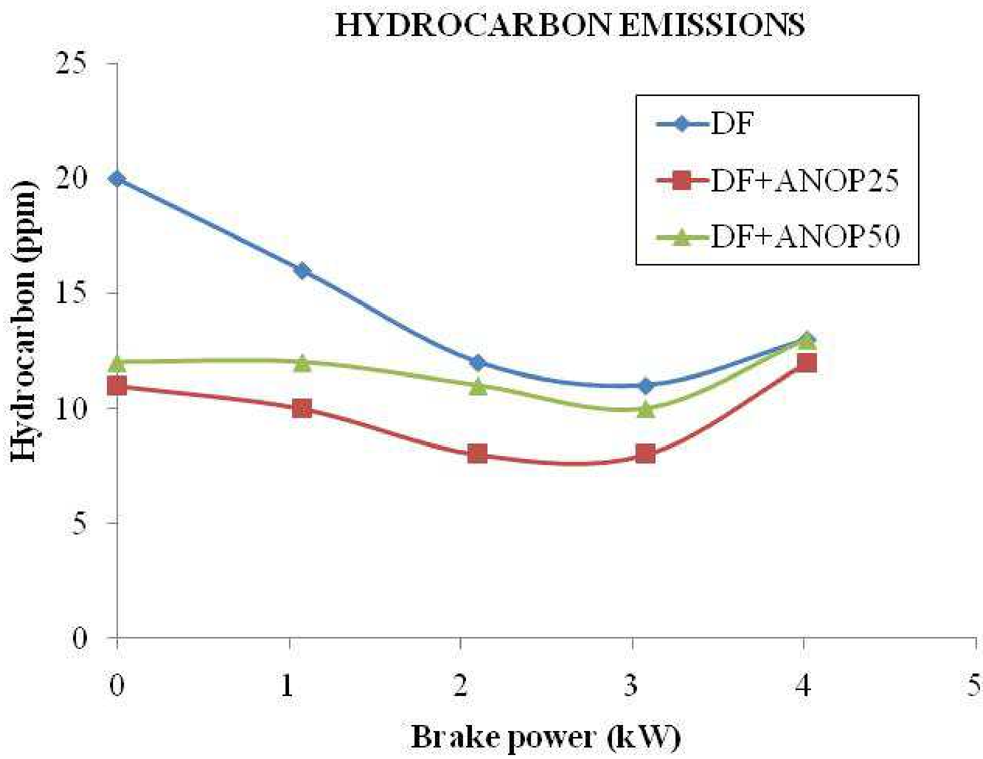

Figure 7 Hydrocarbon Vs Brake power

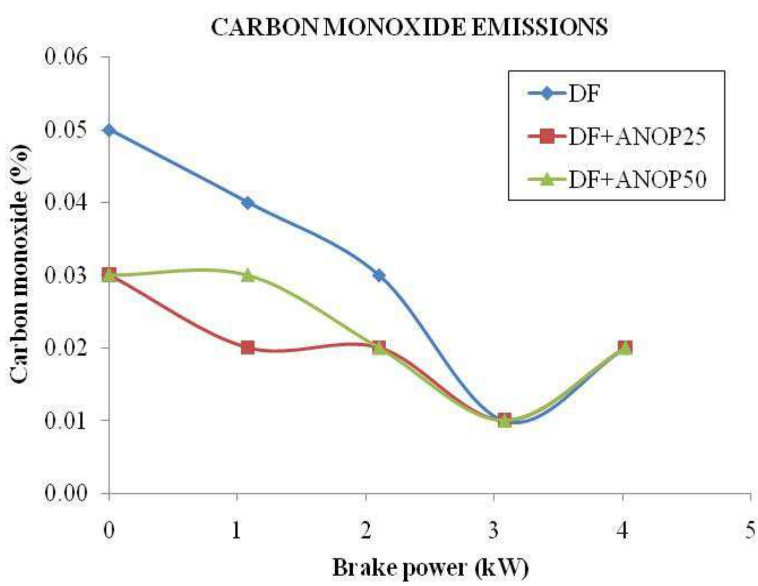

Figure 8 Carbon monoxides Vs Brake power

5.2.3 Oxides of nitrogen

Fig.9 shows NO_x emission with and without the addition of nanoparticles on diesel fuel. NO_x emission is mainly depended on temperature, the local concentration of oxygen and the duration of combustion during different combustion phases on the different combustion zones. The nanoparticles possess high surface areas which increase their chemical reactivity which in turn reduces the ignition delay. Earlier carbon combustion activation increases their in-cylinder temperature at all loads compared to diesel fuel. Among the blends DF+ANOP50 shows lower NO_x

emission than other concentration. A drastic increase of 23% in NOx emission was obtained with respect to diesel fuel.

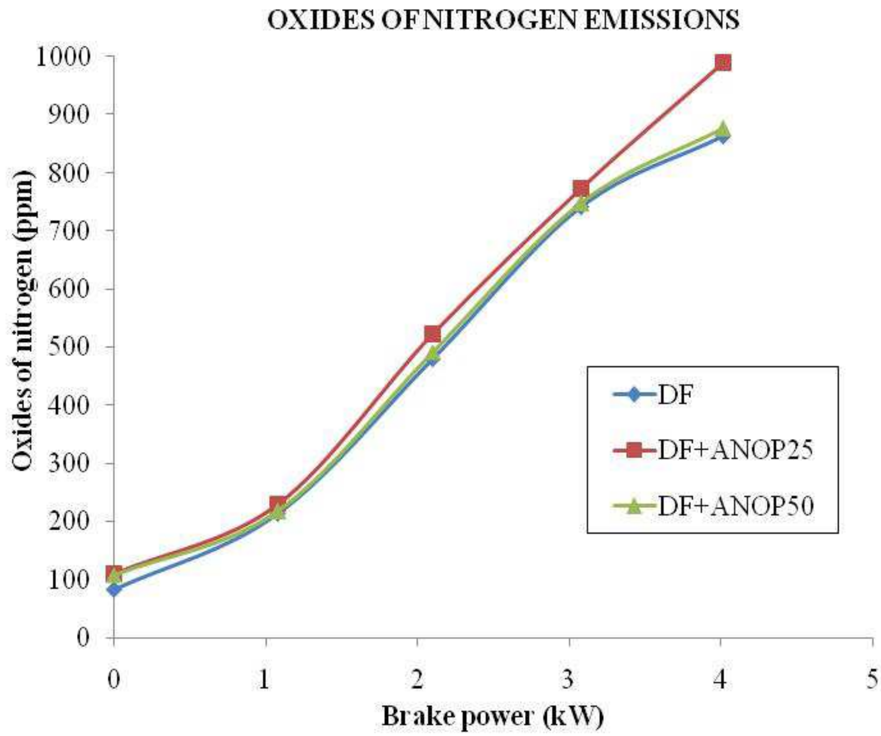

Figure 9 Oxides of nitrogen Vs Brake power

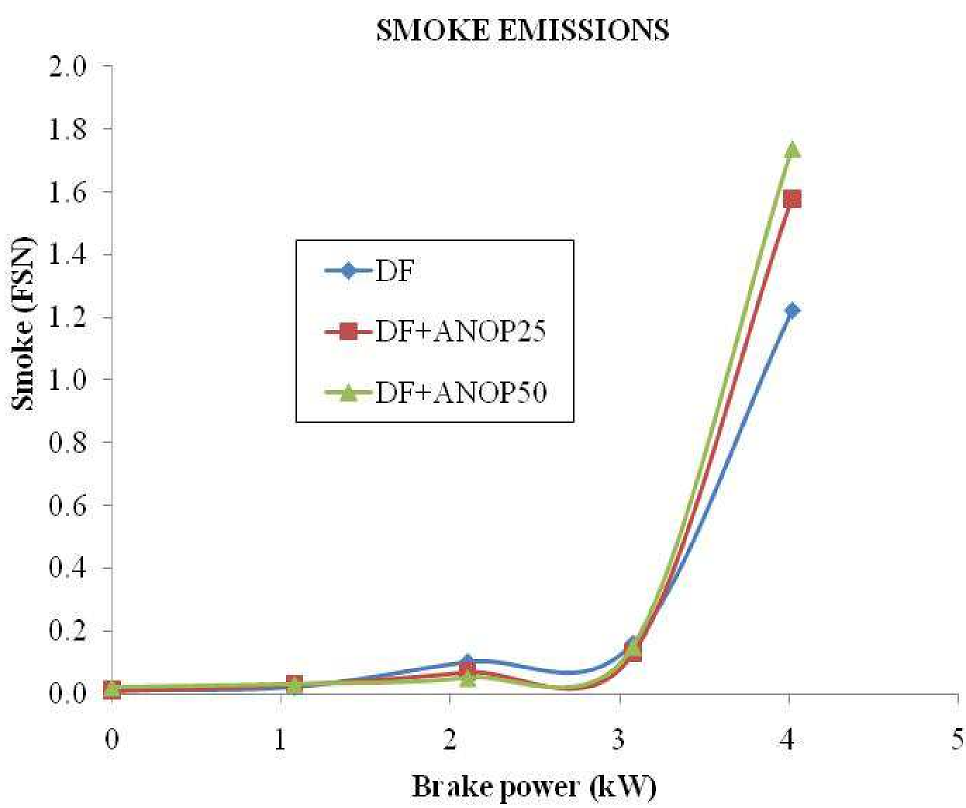

Figure 10 Smoke emissions Vs Load

5.2.4 Smoke emission

Fig.10 shows the variation of smoke emission with respect to brake power for DF, DF+ANOP25 and DF+ANOP50 fuels. It is observed that as the load increases, the smoke density gradually increases in all cases. For DF+ANOP25, the smoke emission varies from 0.01 FSN at no load to 1.58 FSN at maximum load, which is lower than the diesel fuel, except at higher load condition. Further the addition of nanoparticles significantly increases the smoke emission at higher load. This may be due to poor mixing of air-fuel mixture and insufficient oxygen at higher load. The smoke emission of DF+ANOP25 and DF+ANOP50 decreases about 20–30%, especially at moderate load conditions. It was also observed that the smoke emission increases with the addition of nanoparticles.

5.3. Combustion parameters

5.3.1. Cylinder pressure

Fig.11 shows the variation of cylinder pressure with respect to crank angle for diesel and modified diesel blend with the addition of aluminium oxide nanoparticles at different engine operating conditions. As the engine load decreases, the wall temperature and residual gas temperature have been reduced, which leads to a lower charge temperature at injection timing and lengthens the ignition delay. Addition of nanoparticles tends to reduce the ignition delay and enhances the combustion. It has been observed that there is slight increase in cylinder pressure with all dosage levels of nanoparticles compared to pure diesel fuel. The peak pressure is increased by shortening of the diffusion combustion of nanoparticles blended fuels and increased in-cylinder temperature at all loads. From the fig.11, it is seen that the cylinder pressure for DF, DF+ANOP25 and DF+ANOP50 was 64.017, 66.049 and 64.864 bar, respectively.

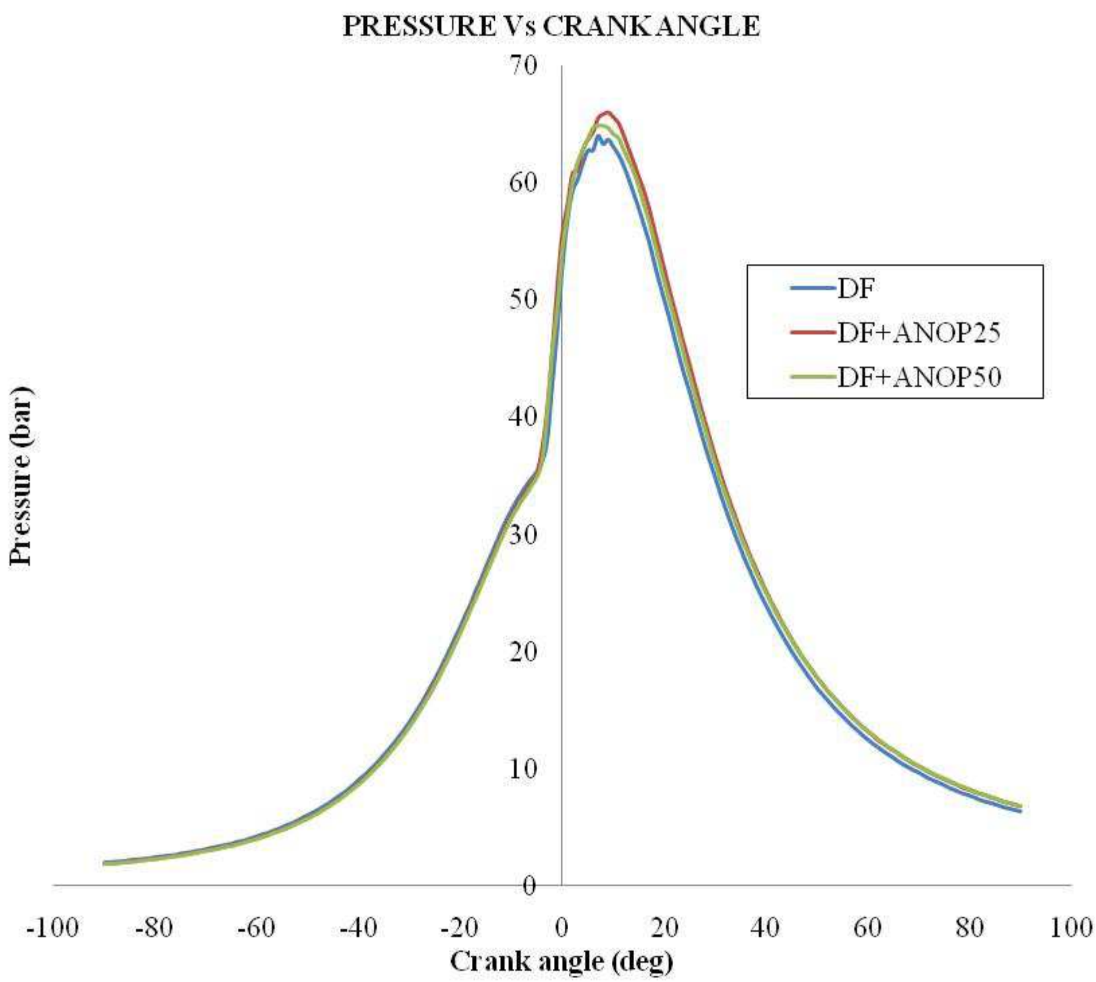

Figure 11 Cylinder pressure Vs Crank angle

5.3.2. Heat release rate

Fig.12 shows the variation of heat release rate with respect to crank angle. The addition of nanoparticles increases higher carbon combustion activation and hence promotes the complete combustion. From the fig.12 it is clear that heat release rate was found to be decreased with the addition of aluminium oxide nanoparticles with respect to pure diesel. High surface area of nanoparticles increases the chemical reactivity of the fuel which accelerates the combustion process and reduces the ignition delay. Shortened ignition delay promotes lesser fuel-air participation for combustion and thereby reduced heat release was obtained during the combustion process. Aluminium oxide nanoparticle promotes controlled combustion rather than rapid combustion. The value of heat release rate is 93.774, 80.440 and 80.025 kJ/m^{3}deg for DF, DF+ANOP25 and DF+ANOP50, respectively.

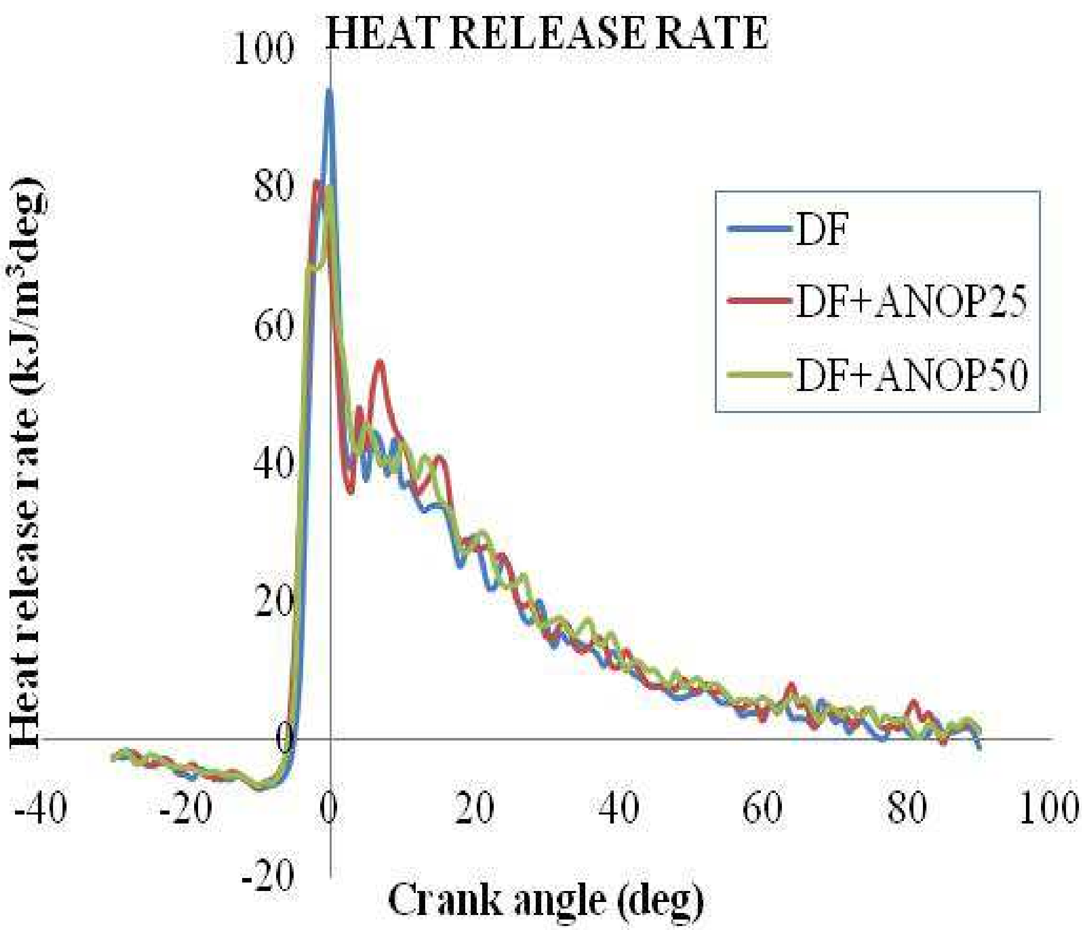

Figure 12 Heat release rate Vs Crank angle

CONCLUSION

The performance, emission, and combustion characteristics of a single cylinder diesel engine using diesel (DF) and modified diesel (DF+ANOP25 and DF+ANOP50) fuels were analyzed. Based on the investigation, the following conclusions are drawn.

- The specific fuel consumption is higher for neat diesel fuel and it has reduced with the addition of AONP.
- A small improvement is observed with the addition of AONP with diesel fuel.
- With the use of AONP in diesel fuel the CO emissions decreases except at higher load conditions.
- The addition of AONP decreases the HC emissions when comparing with neat diesel.
- The NOx emission was found to be drastically increased with the addition of AONP with diesel fuel.
- The addition of AONP in diesel fuel reduces the smoke emission except at higher load.

• There is slight increase in peak pressure with the addition of AONP in diesel fuel due to reduced ignition delay and in-cylinder temperature.
• The heat release rate decreases with the addition of AONP in diesel fuel due to earlier carbon combustion activation.

NOMENCLATURE

COV	Coefficient of variation
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbon
NOx	Oxides of nitrogen
DF	Diesel Fuel
DF+ANOP25	Diesel + 25ppm Aluminium oxide nanoparticles
DF+ANOP50	Diesel + 50ppm Aluminium oxide nanoparticles
SEM	Scanning electron microscope
Ppm	Parts per million
Rpm	Revolutions per minute
FSN	Filter smoke number

Acknowledgement
We thank the management of Sri Venkateswara College of Engineering for providing us with the necessary experimental setup to perform this research work.

REFERENCES

[1] Rolvin D'Silva, Binu K.G, Thirumaleshwara Bhat, *International Conference on Materials Processing and Characterization*, **2015**, 2 (1), 3728-3735.
[2] J.Sadhik Basha, R.B.Anand, *Alexandria Engineering Journal*, **2014**, 53 (1), 259-273.
[3] Mu-Jung Kao, Chen-Ching Ting, Bai-Fu Lin, Tsing-Tshih Tsung, *Journal of Testing and Evaluation*, **2007**, 36 (2), 1-8.
[4] A.Selvaganapthy, A.Sundar, B.Kumaraguruban, P.Gopal, *ARPN J.Sci Technol*. **2013**, 3 (1), 112-115.
[5] Rakhi N.Mehta, Mousumi Chakraborty, Parimal A.Parikh, *Fuel* , **2014**, 120 (1), 91-97.
[6] M. B. Shafii, F. Daneshvar, N. Jahani, and K.Mobini, *Advances in Mechanical Engineering*, **2011**, 3 (1), 1-5.
[7] V. Arul Mozhi Selvan, R.B.Anand, M.Udayakumar, *Fuel*, **2014**, 130 (1), 160-167.
[8] M.A.Lenin, M.R.Swaminathan , G.Kumaresan, *Fuel*, **2013**, 109 (1), 362-365.
[9] Rakesh Kumar Maurya, Avinash Kumar Agarwal, *Applied Energy*, **2012**, 89 (1), 228-236.