Effect of Nanoparticles on the Emissions of a CI Engine

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Abstract- Diesel engines are a major source of contributors of emissions such as carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter. An effort has been made to reduce the emission of such noxious gases by the addition and use of oxidizers in the conventional fuel. Neat Diesel is blended with Aluminium Oxide nanoparticles, Zinc Oxide nanoparticles and Iron Oxide nanoparticles. The blending operations were carried out using a probe type ultrasonicator. Flash point and fire point of the blended diesel showed a marked increase, whereas kinematic viscosity showed marginal decrease. Performance tests were carried out on Kirloskar AV1 single cylinder engine. Results show a decrease in the concentration of the pollutants with the use of nanoparticles, which may be attributed to the oxidizing nature of the nanoparticles.

Keywords- Aluminium Oxide; Zinc Oxide; Iron Oxide; Nanoparticles; Diesel Emissions; Probe Type Ultrasonicator.

1. Introduction

Majority of commercial vehicles use diesel engine as a source of power for their mobility. While diesel engines offer some unique advantages such as better thermal efficiency, fuel economy and reliability, they also produce a large quantity of pollutants, such as CO, HC, NO_x, PM and RSPM due to incomplete combustion happening within the combustion chamber. Among these pollutants, CO ranks first followed by HC [1]. The problem of pollution can no longer be ignored in the present scenario. The above mentioned gases have been found to cause heart disease and breathing problems, cancer and reproductive disorders, environmental hazards such as acid rain and ground level ozone formation, and respiratory problems such as asthma. Therefore, the need arises to ensure the occurrence of complete combustion within the combustion chamber.

Nano metal oxide additives are reported to be successful in reducing diesel emissions to a great extent and known as solid oxygenators. These solid oxygenators reduce diesel engine emissions as well as diesel consumption. The AONP exhibit peculiar thermal behaviour because of its stored internal energy [2, 3]. Aluminium nano fluids when mixed with diesel, show a good improvement in reducing HC and CO emissions [4]. Lower Ignition delay, faster reactivity and quicker energy release rates are due to the increased surface area of the Nano particles which are highly charged [5]. Mixing of ZONP with neat fuel improves combustion efficiency and prompts the catalytic oxidation of the fuel blend [6]. IONP forms condensation sites in combustion zone and burns more carbon thereby reducing soot formation [7]. Tribological behaviour of nanoparticles added to lube oils reduces the friction between the moving surfaces due to deposition of nanoparticles in the scars and grooves on the surfaces of the combustion chamber [8]. In this context, an effort has been done to compare the emissions of neat diesel fuel and the fuel blended with solid oxygenators like AONP, IONP and ZNOP in certain proportions.

2. Effect of Nano-Particles as an Additive to Diesel

Nanoparticles are known to exhibit properties that are vastly different from that of bulk materials, on account of their high surface area to weight ratio. These properties include better thermal conductivity and catalytic activity. S Karthikeyan et. al [9] found that CO and HC levels decreased, whereas NO_x and CO_2 levels were found to increase when ZONP was added to Grape Seed Oil Methyl Ester blends. Prabhu et. al [10] reported that CO, HC as well as smoke emissions decreased when TONP were added to Diesel-Biodiesel blends. V.Arul Mozhi et. al [11] in their investigations have shown drastic reduction in HC and NOx emissions when using CONP with Diesel-Biodiesel blends, which acts as an oxygen donating catalysts. Syed Alam et. al. [12] reported that CO, HC and smoke emissions reduced whereas NO_x emissions increased with the use of AONP in Diesel. M Santhanamuthu et. al. [13] have found that the addition of IONP was found to have little effect on the emissions when used with Polanga Oil – Diesel blends. Narasimhalu et. al [14] in their work have showed that CO and HC emissions marginally decreased with the use of SNP in Honge Oil Methyl Ester. K Balamurugan et. al [15] in their work have shown no improvements in CO, HC and CO_2 levels with the use of CNP in Soyabean - Biodiesel blends. Vishwajit et. al [16] found that CO and HC emissions decreased marginally when GNP were used in Honge Oil Methyl Ester. Sadik Basha et. al [17] in their work have shown that the addition of CNT with Jatropha Methyl Ester emulsions were found to reduce HC emissions marginally and CO emissions appreciably.

3. Fuel Blend Preparation

The AONP, IONP and ZONP were acquired from Sigma Aldrich. The properties of the nanoparticles are mentioned in Table 1, Table 2, and Table 3. Required quantities of each nanoparticle were weighed using an electronic balance. The blending process were carried out using a probe type ultrasonicator as shown in Fig. 1, so as to ensure the de-agglomeration of the nanoparticles. This is achieved by the shear forces applied on the nanoparticle agglomerates due to cavitation occurring within the fuel mixture.

Table 1 Properties of AONP

Sl. No.	Parameter	Aluminium Oxide Nanoparticles
1	Manufacturer	Sigma Aldrich, Bangalore
2	Average Particle Size	≤ 50nm
3	Formula	Al_2O_3
4	Formula Weight	101.96 g/mol
5	Appearance	White
6	Form	Powder

Table 2 Properties of IONP

Sl. No.	Parameter	Iron (III) Oxide Nanoparticles
1	Manufacturer	Sigma Aldrich, Bangalore
2	Average Particle Size	35nm
3	Formula	Fe_2O_3
4	Formula Weight	159.69 g/mol
5	Appearance	Brown
6	Form	Powder

Table 3 Properties of ZONP

Sl. No.	Parameter	Zinc Oxide Nanoparticles
1	Manufacturer	Sigma Aldrich, Bangalore
2	Average Particle Size	67nm
3	Formula	ZnO
4	Formula Weight	81.39 g/mol
5	Specific Surface Area	16 m^2/g
6	Appearance	White
7	Form	Powder

Thus, six fuel blends were obtained i.e., Al-80 (dispersion of AONP in Diesel in the mass fraction of 80ppm), Al-100 (dispersion of AONP in Diesel in the mass fraction of 100ppm), Fe-100 (dispersion of IONP in Diesel in the mass fraction of 100ppm), Fe-200 (dispersion of IONP in Diesel in the mass fraction of 200ppm), Zn-80 (dispersion of ZONP in Diesel in the mass fraction of 80ppm) and Zn-100 (dispersion of ZONP in Diesel in the mass fraction of 100ppm).

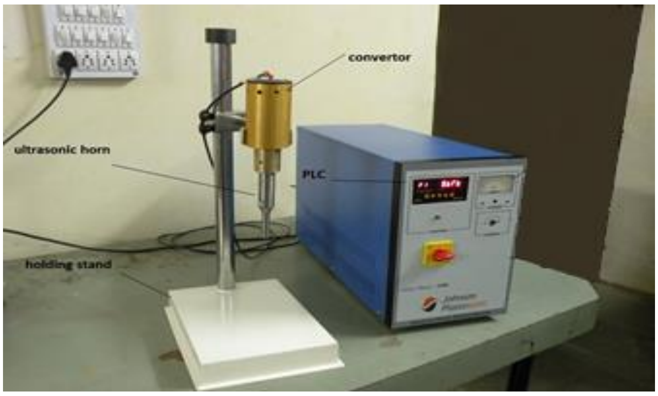

Fig. 1 Probe Type Ultrasonicator

4. Fuel Testing

The fuel samples were tested for calorific value, flash point, fire point, and kinematic viscosity as per ASTM standards. The results were tabulated in Table 4.

Table 4 Properties Results of the Tested Fuel Samples

Fuel	GCV (Kcal/Kg)	Flash Point (^{0}C)	Fire Point (^{0}C)	Kinematic Viscosity @40^{0}C (m^2/sec)
Diesel	10160	42	52	1.06x10-05
Al-80	10480	68	75	8.59x10-06
Al-100	10440	71	76	9.72x10-06
Fe-100	10210	69	79	9.89x10-06
Fe-200	10170	72	81	9.77x10-06
Zn-80	10510	64	69	8.97x10-06
Zn-100	10470	70	75	9.79x10-06

The results indicate a considerable increase in flash point as well as fire point, which indicates that the volatility of fuel decreases with the blending of nanoparticles. Further, the storage of the fuel becomes safer due to decreased flash and fire points, fuel blend's stabilization could be improved and achieved by the addition of surfactants. The kinematic viscosity of the fuel blends were found to decrease marginally, which in turn improves the combustion characteristics of the fuel marginally since the fuel may be sprayed more efficiently.

The fuel blends however were not found to be very stable as there was slight precipitation of nanoparticles with time. Fe-100 and Fe-200 showed high amounts of precipitation within 12 hours whereas the other fuel blends showed only slight precipitation after a week.

5. Experimental Setup

The engine used is Kirloskar AV1 single cylinder water cooled DI diesel engine. Fig. 2, shows the experimental setup in the laboratory. The engine loading was done by means of an electric dynamometer fixed to the engine's output shaft. The specification of the engine is mentioned in Table 4.

Table 1 Engine Specification

Engine Type	4 stroke Single cylinder diesel engine
Manufacturer	Kirloskar AV 1
Loading	Electric Dynamometer
Rated power	3.7kW at 1500rpm
Bore and Stroke	80mm x 110mm
Cylinder capacity	553cc
Compression ratio	16.5:1
Starting	Manual Hand crank

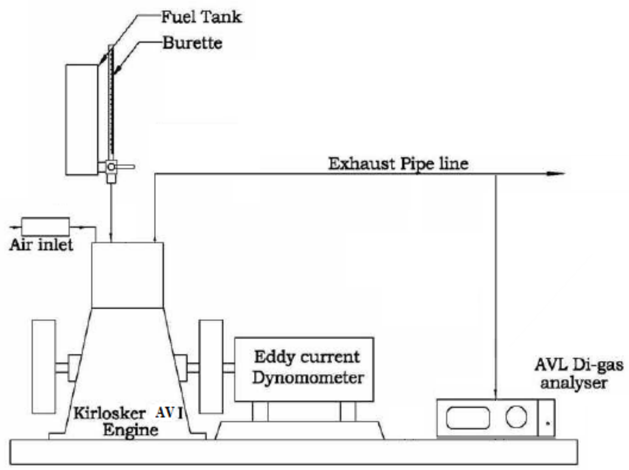

Fig. 2 Line Diagram of Experimental Setup

6. Experimentation

Emission testing was carried out under zero loading, half loading and full loading conditions. The effect of injection pressure was investigated by measuring the emissions at three different injection pressures namely 180 bar, 200 bar and 220 bar. Emission results were obtained using the AVL DIGAS 444 ANALYSER. The emission levels of CO, HC and CO_2 were noted for each of the above mentioned operating conditions.

7. Emission Characteristics

7.1. *Results at 180 bar*

7.1.1. *Variation of CO Emission*

At 180 bar, it was found that there was not much correlation among emission results at zero load which is shown in Fig. 3. However, CO emissions reduced significantly at half load and at full load. Zinc Oxide blends showed improved reduction in CO emissions with concentration. Up to 40% decrease in emission was observed the u

se of Zn-100 and Al-80.

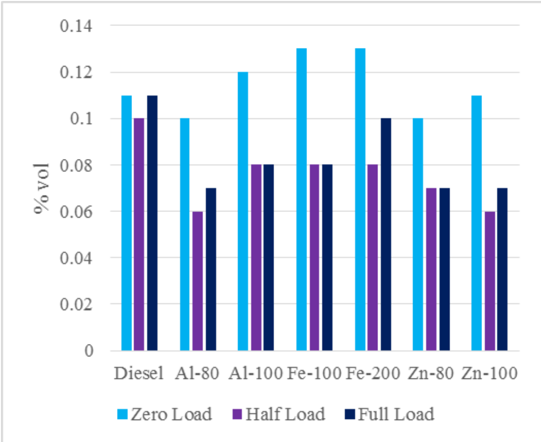

Fig. 2 Variation of CO vs. loading at 180 bar

7.1.2. *Variation of HC Emissions*

HC emissions were found to decrease at all levels of loading with the use of Al-80, Al-100, Zn-80, and Zn-100. However, Fe-100 and Fe-200 showed an increase in HC levels as shown in Fig. 4. These trends were found to increase with the concentration. Al-100 showed up to 15.73% decrease in emission whereas Zn-100 showed 38.81% decrease in emission.

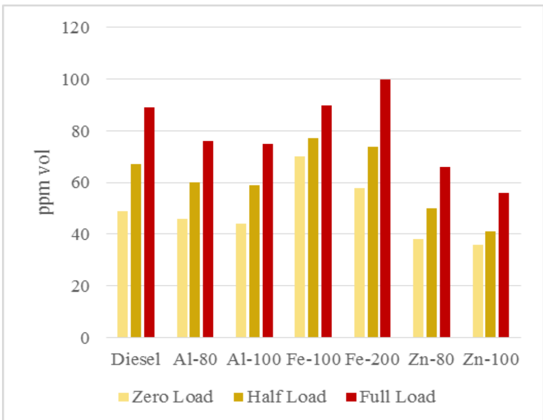

Fig. 3 Variation of HC vs. loading at 180 bar

7.1.3. Variation of CO_2 Emissions

The emission of CO_2 was found to increase marginally, especially at full load. Al-100, Fe-100, Fe-200, and Zn-100 always showed increased CO_2 emissions at all loading conditions, indicating a more efficient combustion reaction. Al-100 and Zn-100 showed increase in emission by up to 8.75% and 6.98% respectively. It is to be noted that Fe-100 and Fe-200 gave highly similar results, indicating that there might not be much improvement in emission levels by increasing the concentration of IONP as shown in Fig. 5. ZONP blends showed increasing emissions with increasing concentrations, indicating better combustion with increasing concentrations.

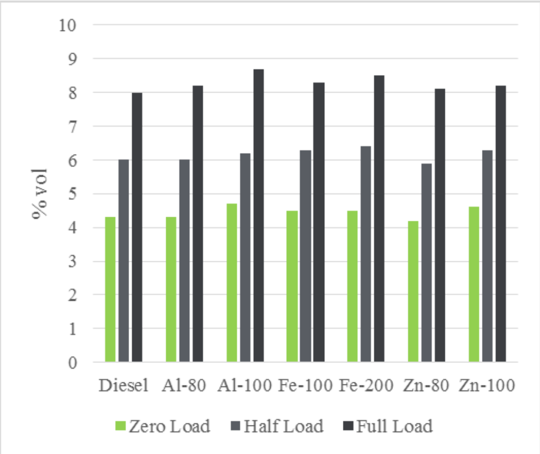

Fig. 4 Variation of CO_2 vs. loading at 180 bar

7.2 Results at 200 bar

7.2.1. Variation of CO Emissions

The variation in CO emissions were observed to follow the trend seen at injection pressure of 180 bar.Al-80 showed up to 37.5% decrease in emission whereas Fe-200 and Zn-80 showed up to 25% reduction in CO emissions as shown in Fig. 6.

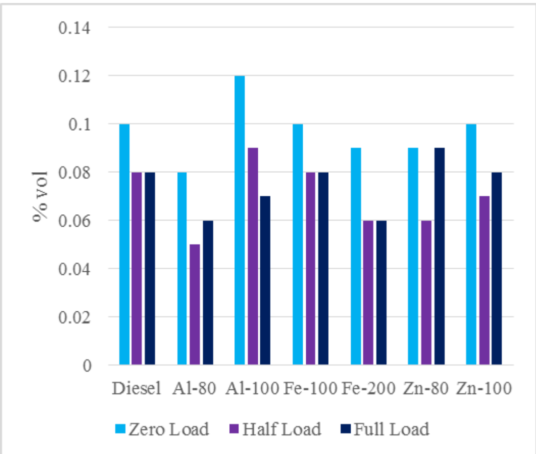

Fig. 5 Variation of CO vs. loading at 200 bar

7.2.2. Variation of HC Emissions

At 200 bar, the trend seen in HC emission at 180 bar were continued, with the exception of IONP blends. Here, it was found that emissions decreased with the use of IONP also. It is to be noted that Zn-80 showed marginal increase in emissions, while Zn-100 showed a remarkable decrease in emissions as shown in Fig. 7. Zn-100 showed up to 42.16% decrease in emissions, while Al-80 showed up to 36.27% decrease in emissions.

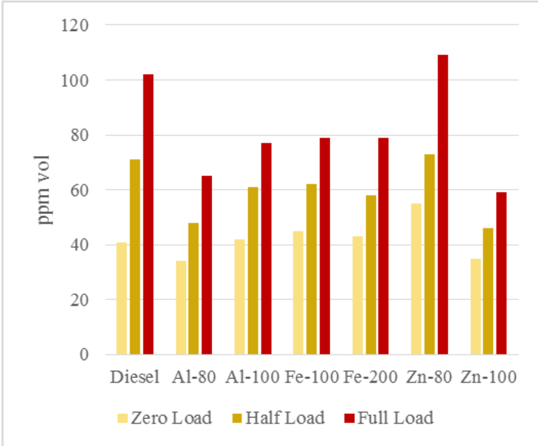

Fig. 7 Variation of HC vs. loading at 200 bar

7.2.3. Variation of CO_2 Emissions

The trend observed here were similar to those at 180 bar. Emission was found to decrease marginally with increase in concentration of IONP. However, increasing concentrations of AONP and ZONP were found to increase emission levels quite significantly as shown in Fig. 8. Al-100 showed up to 21.05% increase in emissions.

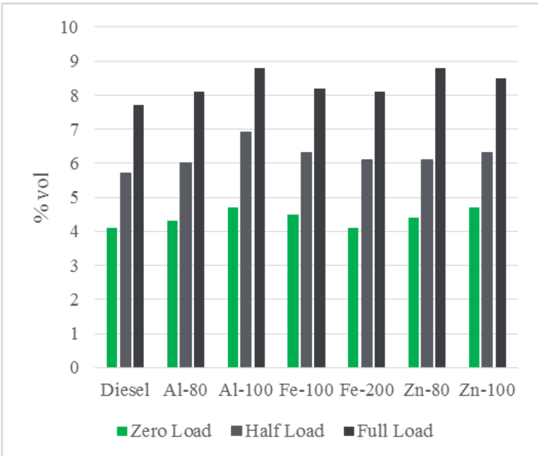

Fig. 8 Variation of CO_2 vs. loading at 200 bar

7.3. Results at 220 bar

7.3.1 *Variation of CO Emissions*

Emissions were found to decrease at lower levels of loading with Al-80 and Al-100. It appears that the decrease in emissions decreases with increase in loading. Fuel blends containing IONP were found to remain the same at lower levels of loading, while at full load these emissions were found to increase. Zn-80 showed considerable decrease in emissions as shown in Fig. 9. Zn-100 showed no change in emission at low loads however there was marginal increase in emissions at full load.Zn-80 showed up to 25% decrease in emissions at half load.

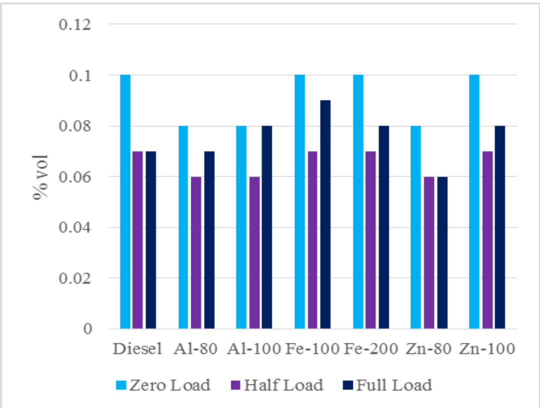

Fig. 9 Variation of CO vs. loading at 220 bar

7.3.2. Variation of HC Emissions

Emission of HC followed the same trend that was observed at 180 bar. Here, the only point of difference was the emissions of Fe-100 and Fe-200. Although both these fuels showed marked increase in emission levels in comparison to diesel, it was observed that with increasing concentration of IONP, HC emissions decreased as shown in Fig.10. Zn-100 showed up to 21.25% decrease in emissions at full load.

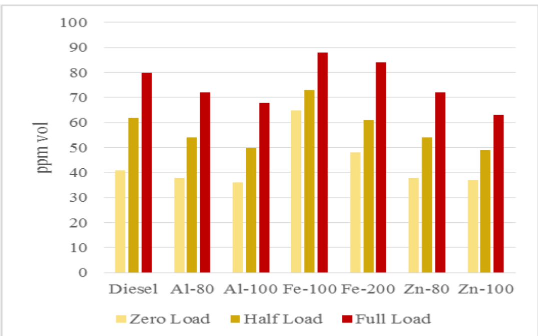

Fig. 10 Variation of HC vs. loading at 220 bar

7.3.3. Variation of CO_2

It was observed that there was an increase in emission levels at full load, however there was only a marginal amount of change (both increase and decrease) at lower levels of loading. Increase in concentration of nanoparticles, in general, was found to increase the emission of CO_2, except in the case of IONP blends at lower loads. Al-100 showed up to 7.5% increase in emissions at full load as shown in Fig.11.

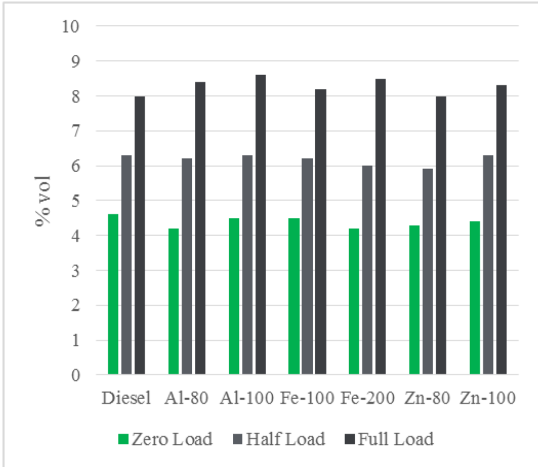

Fig. 11 Variation of CO_2 vs. loading at 220 bar

8. Conclusion

The emission characteristics of AONP, IONP and ZONP-Diesel blends were investigated. Based on the above observation, the following conclusions are drawn-

1) Each of the fuel blends shows a considerable improvement in GCV as compared to diesel. GCV was observed to decrease slightly with increase in concentration of nanoparticles.
2) Each of the fuel blends shows a drastic increase in flash point as well as fire point. Both flash and fire points increase with increase in concentration of nanoparticles.
3) Each of the fuel blends shows a marginal decrease in kinematic viscosity at 40^0C. This drop showed marginal decrease with increase in concentration of nanoparticles.
4) CO emissions were found to decrease significantly with AONP-Diesel blends at lower injection pressure i.e. 180 bar. This decrease however tends to decrease with increase in fuel injection pressure.
5) With IONP-Diesel blends, at 180 bar CO emissions were found to decrease significantly. At 200 bar, the decrease in CO emission increased with concentration. At 220 bar, CO emissions were found to increase marginally.
6) The use of ZONP-Diesel blends reduced the emissions of CO at all injection pressures. However, at lower injection pressures (i.e. 180 bar) the decrease in CO emissions increased with the concentration of nanoparticles.
7) The use of nanoparticle-Diesel blends decreases the emission of HC. This trend saw an exception in the cases of IONP-Diesel blends. However, at all the injection pressures, the increase in concentration of nanoparticles in the blend will the increase the HC emissions.

8) The addition of nanoparticles in Diesel indicates an improvement in the combustion reaction, which is evident by an increase in CO_2 emissions. Also this phenomenon is found especially at lower injection pressures.

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Nomenclature

AONP	Aluminum oxide Nano particle
CNP	Copper Nano particle
CNT	Carbon Nanotubes
CO	Carbon monoxide
CONP	Cerium oxide Nano particle

Nomenclature

DI	Direct Injection
GCV	Gross Calorific Value
GNP	Graphene Nano particle
HC	Hydrocarbons
IONP	Iron Oxide Nano particle
NO_x	Oxides of nitrogen
PM	Particulate matter
RSPM	Respirable Suspended Particulate Matter
SNP	Silver Nano particle
TONP	Titanium oxide Nano particle
ZONP	Zinc oxide Nano particle