Experimental investigation on performance, combustion and emission characteristics of nanoparticle blends with diesel as fuel in a CI Engine

PARA AKHIL[1], SHARMILA PARASHAR[1], POONAM KOLAPE[1], M. FEROSKHAN[1], P. TAMILSELVAN*,[1]

*Corresponding author
[1]School of Mechanical Engineering, Vellore Institute of Technology (VIT) Chennai, Tamilnadu - 600127, India,
feroskhan.m@vit.ac.in, tamilselvan.p@vit.ac.in*

DOI: 10.13111/2066-8201.2022.14.3.4

Received: 17 January 2022/ Accepted: 05 July 2022/ Published: September 2022

Abstract: *The present work has discussed the following characteristics like performance, combustion and emission characteristics of blends of aluminum (Al), zinc oxide (ZnO) and its mixture of nanoparticles at different ratios with diesel tested on a stationary direct injection compression ignition (CI) engine at five different loads. The fuels have been made by blending of nanoparticles with diesel at different concentrations. The results have shown that the Nano fuels have given lower brake specific fuel consumption (BSFC), higher brake thermal efficiency (BTE) and air-fuel ratio when compared with diesel. In combustion analysis, the Nano fuels have given higher heat release rate, crank angle 50 (CA50) and lower ignition delay when compared with diesel. In emission analysis, the Nano fuels have given higher nitrogen oxides (NO_x) and lower carbon monoxide (CO), hydrocarbons (HC) and smoke emissions when compared with diesel. The fuel properties of nano fuels have shown that the kinematic viscosity, calorific values have been higher and flash point, fire point, density have been lower when compared with diesel.*

Key Words: *Performance parameter, combustion characteristics, Emission characteristics, nano particles*

1. INTRODUCTION

The socio-economic status of any nation has always been greatly influenced by efficient conversion of energy. There are currently various energy conversion devices in the world and one of them is the diesel engine. Diesel engines are still accepted as one of the best among various energy conversion devices due to their amazing features/ characteristics, like low specific fuel consumption (SFC), higher thermal efficiencies ($\eta_{thermal}$) and compression ratio, reliability and also application of leaner air-fuel mixtures. They are used for several purposes like electricity generation, machines supporting advanced farming (technology) in agriculture, automobile sector, ships, transportation through railways, etc., due to their low operating and maintenance cost. Despite of having the extra ordinary qualities, diesel engines emit a huge amount of pollutants like NO_x, CO_2, CO, soot, acrolein and formaldehyde due to which they have caused dangerous health problems and also environmental degradation. Also, with the increasing rate of population growth and high usage rate, the demand for energy has increased which has led to a diminishing of fossil fuels gradually. In India, a huge gap has been observed between the diminution and use of petrol based fuel along with the possibility of it being produced in the country and also the possibility of buying crude oil from other OPEC countries. The above-mentioned factors have greatly influenced the economic growth rate of almost all developing countries including India. Keeping the present situation in mind, engine manufacturers have come up with modified engine designs to get better efficiency complying with government emission rules to protect the environment. But these efforts have not been enough to overcome the problems that lead the scientific community to look for better alternative fuels, either by creating new fuels or by modifying the existing fuel. The strategies for fuel modification have improved the properties of fuel, mainly combustion characteristics which are responsible for better fuel economy, low emissions and also engine performance. There have been several different ways to modify the fuel, and one among them has been addition of nanoparticles in fuel. This process has given higher combustion enthalpies, in total a rise in energy density, shorter ignition delays, absolute combustion and decreased emissions. From the various studies mentioned above it can be understood that blending of diesel fuel with nanoparticle has shown notable effects on properties of fuel and also on combustion characteristics.

2. LITERATURE REVIEW

The brake thermal efficiency (BTE) have been 2–3% more with the B20 (Biodiesel 20% with nanoparticles +80% diesel) added to 50 ppm and 100 ppm of ZnO when compared with diesel fuel. Also, when compared to all the tested fuels including diesel, the B20 fuel with 50 ppm of ZnO has given the least NO_x emission [1].

In the case of CIME ZnO100 (calophyllum inophyllum methyl ester + ZnO 100ppm) and CIME ZnO50 (calophyllum inophyllum methyl ester + ZnO 50ppm), the better results of BTE, BSFC and BFEC have been found adding ZnO (metal oxide) nanoparticles because of the catalytic effect of nanoparticles and this led to better combustion. Also, HC and CO emissions have decreased adding ZnO nanoparticles as they have acted as an O_2 buffer which have promoted absolute combustion of fuel [2]. By introducing blended fuel to ZnO metal oxide BTE increased at the full load, and it have increased Rate of heat releases, cylinder pressure, calorific value (CV) of fuel which have increased the BSFC. BTE, HRR and in cylinder pressure have been found higher for the blends that have contained nano zinc oxide more than 100 ppm than diesel. From the literatures, it has been observed that nanofluid enhanced the combustion of fuel because of its better air fuel mixing rate, catalytic activity and heat transfer. Most of the additives have showed reduction in HC and smoke because of higher evaporation rate, catalytic oxidation and have reduced ignition delay and NO_x have reduced because of higher cetane number. The CO emission has been also reduced because of complete combustion of the fuel. Some have observed an increase in CO emission and others have noticed a decrease in CO emission because of improvement in ignition characteristics by adding nanoparticles in fuel. CO emission has increased at high concentration of nanofluid additives [3]. BTE has increased by 9% and BSFC, HC and CO emission have decreased 7%, 4% and 4% respectively, by adding aluminum to fuel when compared to diesel [4].

Because of micro explosion phenomena, BTE of the engine increased by raising the concentration of water in emulsion fuel. In most of the papers better BSFC, BP ant torque have been found with W/D (water in diesel) emulsion fuel. Inconsistent improvements have been observed for HC and CO emissions because of the complicacy of analysing the combustion behaviour linked with micro-explosion, track of emulsion, also soot formation. Using W/D emulsion fuels NO_x emission was reduced by 45% [5]. At lower engine speeds less than 1800 r/min BSFC, NO_x and smoke for aluminium nanoparticle + Diesel fuel were lower when compared to Diesel fuel [6].

Addition of metal and metal oxides nanoparticles to diesel/ biodiesel have resulted in depletion of emissions of HC, CO_2 and NO_x [7].

When compared with conventional diesel fuel and pure CIME the unburned hydrocarbon and CO emissions were lower for all CIME Nano emulsions [2]. Sonication time (Sonication is the process in which the sound energy is used to mix particles in a fluid, for different needs) and concentration of surfactant influence the suspension stability of the nanoparticles in the blended fuels. NO_x emissions have been reduced with the inclusion of nanoparticles. CO emission have increased on adding ZnO nanoparticles in pure JME blends (Jatropha Methyl Ester), and high H_2 flow rate supplemented the CO emission which has decreased the smoke. When compared to H_2 induction without nanoparticles, smoke opacity has been released more due to the presence of the surfactant Triton-X100 [8].

However, THC emission from B10E4 (96% B10 (10% biodiesel + 90% Diesel) + 4% Ethanol) has been much higher compared to B10 (10% biodiesel + 90% Diesel); but compared to B10E4 when Al@C (carbon coated aluminum) nanoparticles have been added in, the THC emission has reduced. For B10E4N30 (96% B10 (10% biodiesel + 90% Diesel) + 4% Ethanol + 30ppm nanoparticles) NO_X emission is reduced by 6% on average [9].

Adding nanoparticles to pure diesel NO_x emission have been increased because of the increase in peak temperature [10].

By going through above literatures, we want to test performance, combustion and emission characteristics of nano fuels at different loads and concentrations. Also, we have decided to make nano fuels by mixing Aluminum, zinc Oxide, and its mixture (ZnO+Al) to diesel at 4 different concentrations which are 15ppm, 30ppm, 45ppm, 60 ppm and have tested at five different loads i.e., 0N-m, 5N-m, 10N-m, 15N-m, 20N-m.

3. EXPERIMENTAL SETUP

A total of 12 nano fuels have been prepared with different ratios i.e., 15, 30, 45, 60 ppm. A 15mg of nanoparticles have been measured using electrical weighing machine and added to one litre beaker filled with diesel. Later, for sonication Process, beaker has been kept in ultrasonicator bath for a time period of 45 minutes to ensure the better mixing of particles which have resulted in nano fuel and have been filled in the bottle along with the sample name on it as shown in Fig. 1.

Similarly, the same process has been repeated for 30, 45, 60 ppm concentrations. After the nano fuels have been prepared, they have been tested in CI engine. The engine specification and schematic diagram are given in Table 1 and Fig. 2, respectively.

The CI engine was started after being sample fed and allowed to run for 20 minutes at a load of 20 N-m. The load was decreased to 0 N-m before taking readings and allowed to reach a steady state. Then readings were taken for speed, gauge differential and the time it took to consume 10ml of fuel. Also, emission readings like smoke, NO_x, CO, HC, CO_2, O_2 emissions have been taken at the outlet of the engine using the sensor detecting probes. Combustion analyser software has been used to record the combustion characteristics.

After that, the load was increased to 5 N-m and the same process was carried out to obtain readings. The same process has been repeated and readings have been taken for 10N-m, 15N-m and 20N-m loads. Table 2 and Table 3 show the input variables used in this study and various blended fuels properties, respectively.

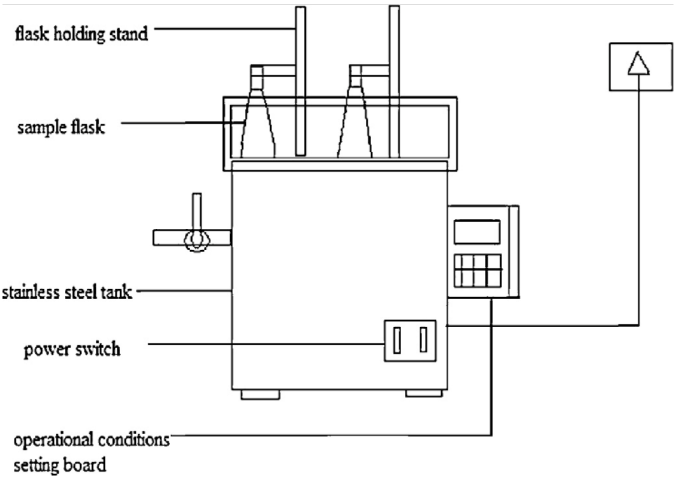

Fig. 1 Ultrasonicator

Table 1. Engine specifications

Sl. No.	Parameters	Specifications
1	No. of Cylinders	1
2	Bore*stroke	80*110 mm^2
3	Cubic Capacity	0.553 L
4	Compression ratio	16.5:1
5	Output	3.7 kW
6	Speed	1500 rpm
7	Torque at full load	0.024 kN-m
8	Crankshaft counter height	203 mm
9	SFC.	195+5% g/kWh
10	Lub oil consumption	0.8%of SFC max
11	Lub oil sump capacity	3.7 L
12	Fuel tank capacity	6.5 L
13	Weight	130 kg
14	Clockwise rotation of flywheel	

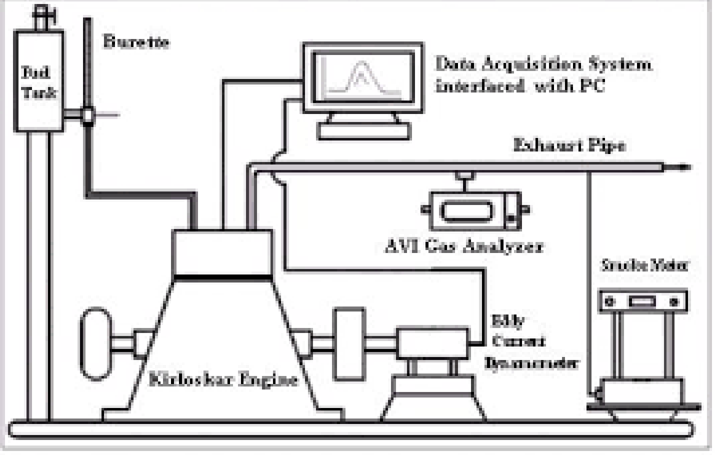

Fig. 2 Schematic Diagram of the set up

Table 2. Input variables

Load (N-m)	Nanoparticles	Concentration
0, 5, 10, 15, 20	Zinc Oxide	15 ppm
		30 ppm
		45 ppm
		60 ppm
	Aluminum	15 ppm
		30 ppm
		45 ppm
		60 ppm
	Zinc Oxide + aluminum	15 ppm (7.5 ppm + 7.5 ppm)
		30 ppm (15 ppm + 15ppm)
		45 ppm (22.5 ppm + 22.5 ppm)
		60 ppm (30 ppm + 30 ppm)

Table 3. Fuel Properties

Sl. No.	Properties	Zno 0 – 15ppm	Zn 0 – 30ppm	Zn0 – 45ppm	Zn0 – 60ppm	Al – 15ppm	Al – 30ppm	Al – 45ppm	Al – 60ppm	Zn0 + Al – 15ppm	Zn0 + Al – 30ppm	Zn0 + Al – 45ppm	Zn0 + Al – 60ppm	Diesel
1	Flash point (°C)	49	48	45	42	42	55	50	48	46	47	46	50	52
2	Fire point (°C)	53	55	52	49	49	62	55	59	52	57	55	55	58
3	Density (kg/m^3)	775	780	790	795	775	780	790	795	780	780	785	790	833
4	Kinematic viscosity at 60°C (mm^2/s)	9.13	9.03	9.45	9.06	9.63	9.35	9.59	9.42	9.28	9.49	8.83	9.41	3.4 (40°C)
5	Calorific value (kJ/kg)	41082	41132	41052	41052	41047	41032	41080	41040	41209	41132	41052	41012	40900

4. RESULTS AND DISCUSSIONS

4.1 Performance characteristics

4.1.1 Brake Specific Fuel Consumption (BSFC)

BSFC value decreased from 0.53, 0.62, 0.55 kg/kWh to 0.232, 0.312, 0.260 kg/kWh for aluminum, ZnO and ZnO+Al, respectively at 15 ppm concentration with increase in load as shown in Fig. 3(a) and Fig. 3(b). This is due to three reasons which are improved, namely, the calorific value, catalytic oxidation and absolute combustion of fuel. For Aluminum and Zinc Oxides, the carbon oxides deposit from the engine leads to productive working of the engine and low fuel consumption. In correspondence to these efficiency characteristics, the specific fuel consumption reduces with a raise in the concentration level of nanoparticles which means that the highest BSFC value has been at 15ppm whereas the lowest value has been observed at 60 ppm (Refer Fig. 3(c)) [3].

As the calorific value of all the samples has been recorded as higher compared to diesel for the same power output of engine, less fuel has been used during pure diesel operation (Refer

Fig. 3(d)). So, brake specific energy consumption (BSFC) has decreased. The highest BSFC value has been recorded as 0.622 kg/kWh at 5 N-m load for ZnO-15ppm sample while the lowest has been observed for ZnO+Al-60 ppm at 20 N-m load as 0.138 kg/kWh.

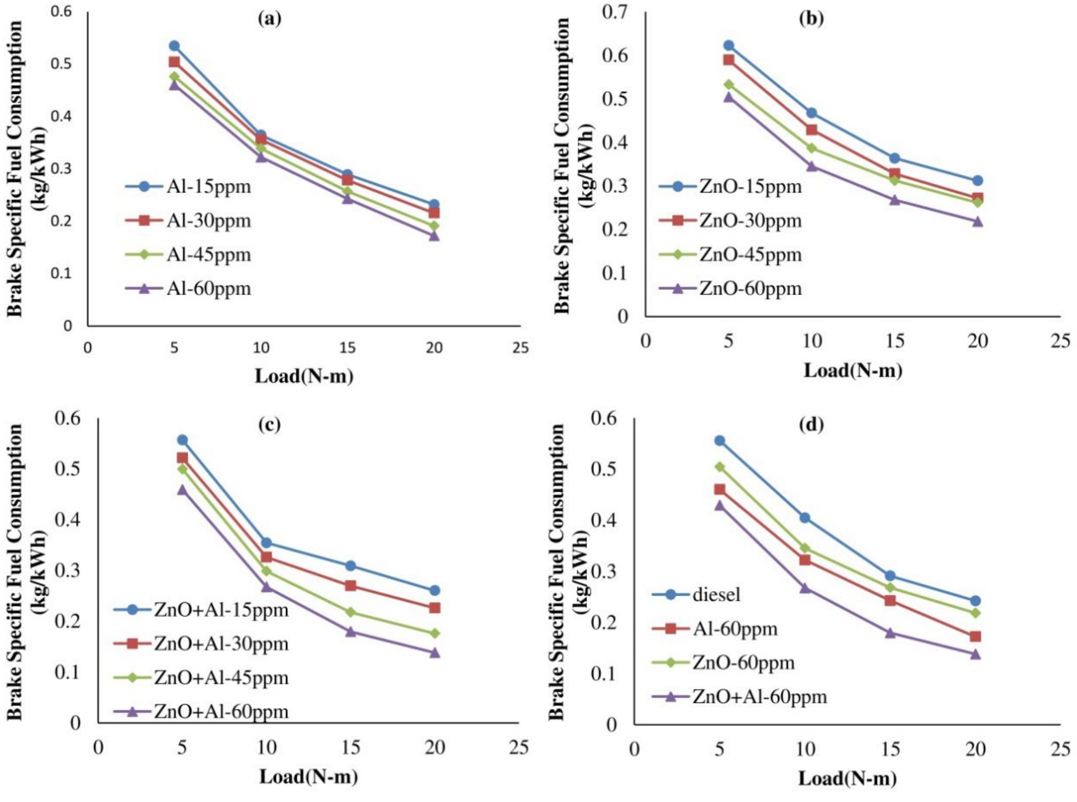

Fig. 3 Variation of BSFC with Load for different concentration of nanoparticles

4.1.2 Brake Thermal Efficiency (BTE)

For Al, ZnO and ZnO+Al, Brake Thermal Efficiency (BTE) increased with increase in load from 17.6%, 13.27%, 15.43% to 31.11%, 30.47%, 30.79% respectively at 60 ppm concentration, as shown in Fig. 4.

It have been observed that, because of the improvement of the calorific values, moreover it also promotes absolute combustion because of higher flame temperatures, lesser ignition delay, higher evaporation rates and prolonged flame sustenance. We have observed increased BTE at higher load with addition of ZnO with diesel [11].

For Al, ZnO and ZnO+Al, BTE increased from 29.078%, 28.08%, 28.58% to 31.11%, 30.47%, 30.79% with increased in dosing of Nano fuels. Due to the oxygenated molecule of the Nanofuel and because of that excess oxygen molecule a complete combustion of fuel occurs which results in maximum efficiency [3].

The BTE was recorded to be higher for all samples compared to diesel fuel due to the occurrence of micro explosion of the primary droplet in the presence of nanoparticles, which leads to increased evaporation rate and is also responsible for the total release of thermal energy, leading to increased BTE. The highest BTE value has been recorded as 31.11% at 20N-m load for Al-60ppm sample while the lowest has been recorded for ZnO-15ppm at 5N-m load as 12.23%.

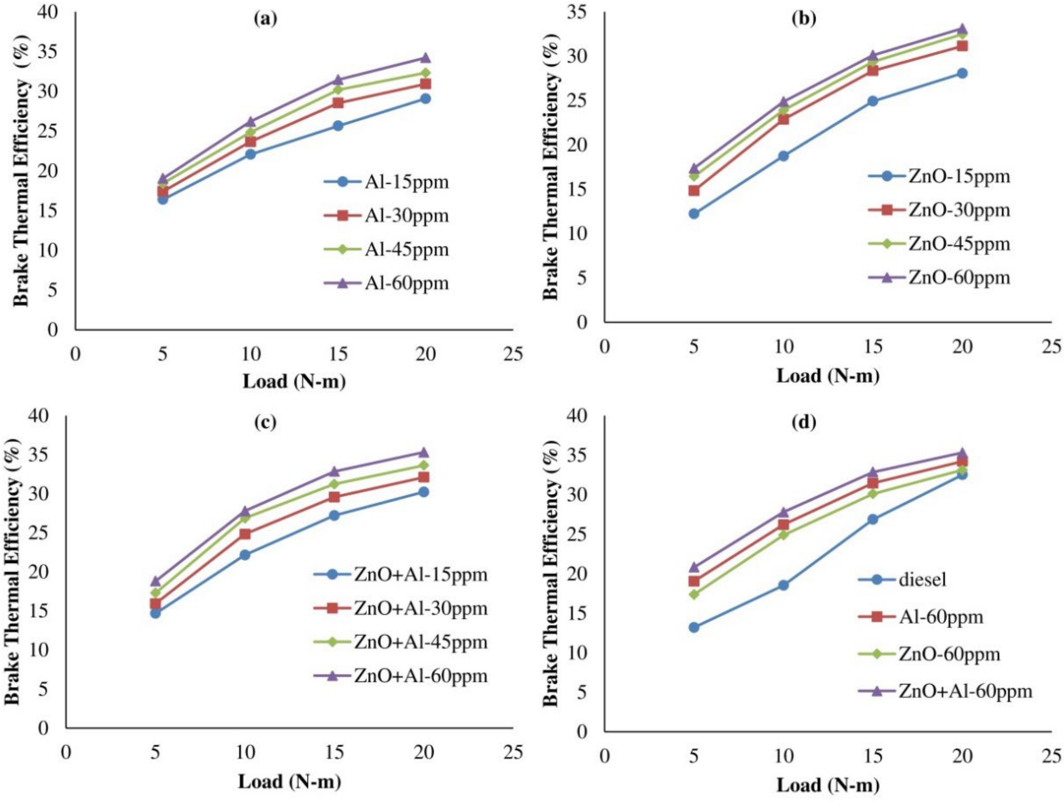

Fig. 4 Variation of BTE with Load for different concentration of nanoparticles

4.2 Combustion Characteristics

4.2.1 Cylinder Pressure

For Al, ZnO, ZnO+Al samples at 60 ppm concentration, Cylinder pressure values increased from 44.30, 43.89, 43.66 bars to 65.92, 65.71, 65.61 bars, respectively with increased load condition from 0N-m to 20N-m load, as shown in Fig. 5.

This have been observed due to the advancement in timing of fuel injection which leads to an early start in the process of combustion, alongside at higher injection pressure small droplets of injected oxygenated diesel fuel promotes faster combustion reactions that leads to increase in the cylinder pressure significantly.

With increased dosing level of nanoparticles from 15ppm to 60ppm in diesel fuel, Cylinder pressure values increased from 65.34, 65.04, 64.86 bar to 65.92, 65.81, 65.73 bar respectively for Al, ZnO, ZnO+Al at 20N-m load.

This might be due to the improved catalytic activity which led to shorter ignition delay with an early initiation in the process of combustion at higher concentration of nanoparticles in blended diesel fuel.

When compared with diesel, nano fuels have higher cylinder pressures which have been observed due to the increased quantity of fuel burned resulting in a raise in the heat energy released which leaded to a raise in peak cylinder pressure [3]; also we observed an increase in Cylinder pressure with the addition of ZnO to diesel [11-12].

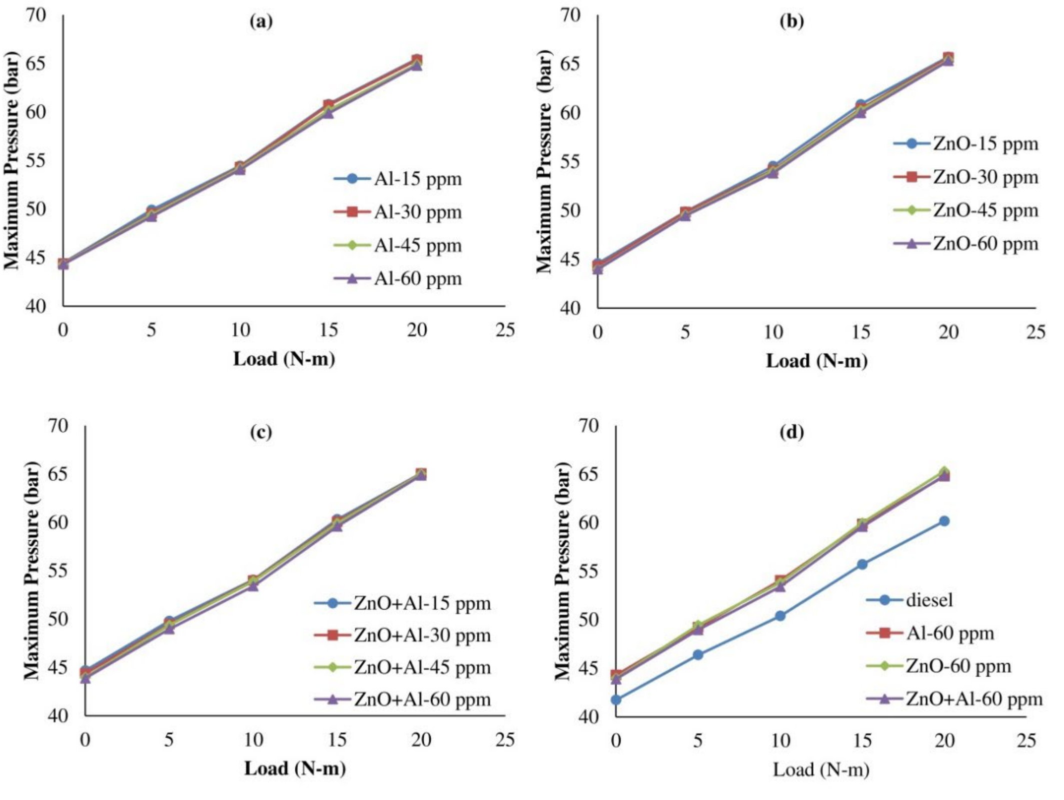

Fig. 5 Variation of Maximum Pressure with Load for different concentrations of nanoparticles

4.2.2 Heat Release Rate (HRR)

As load increased, Heat Release Rate (HRR) also increased from 28, 22, 26 J/CA to 69, 61, 58 J/CA respectively for Al, ZnO, ZnO+Al samples at 60 ppm concentration as shown in Fig. 6.

This has been observed due to the following reason that the shorter ignition delay gives the early coming and better absolute combustion process with high cylinder temperatures and hence resulted in high heat release rates.

With the increased concentration of nanoparticles from 15 ppm to 60 ppm in diesel fuel, heat release rate increased from 61, 62, 56J/CA to 68, 69, 61J/CA respectively for Al, Zno, ZnO+Al Nano fuel blends at 20N-m load condition. This has been observed because of improvement in combustion phase.

Addition of nanoparticles to diesel fuel results in shorter ignition delay with improved ignition properties which results in an early start of the combustion process and hence resulted in increased HRR.

HRR of all samples have been observed as greater than diesel. This has been observed due to higher content of oxygen present in blended fuels that has enhanced the diffusion combustion phase and lessened the combustion time [3].

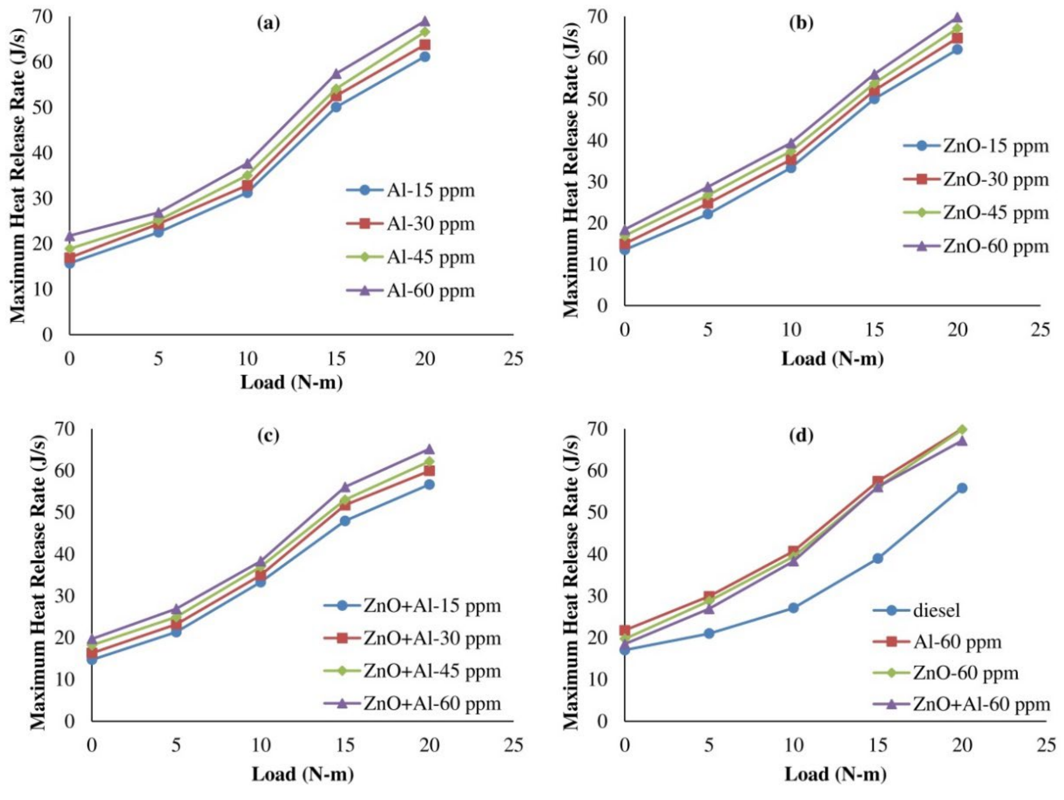

Fig. 6 Variation of Maximum Heat Release Rate with Load for different concentrations of nanoparticles

4.3 Emission characteristics

4.3.1 Carbon Monoxide (CO) Emissions

For all the fuel samples, as load increased, CO emission have been recorded as higher at low loads and started decreasing from 0.025%, 0.028%, 0.035% to 0.01%, 0.013%, 0.015% respectively for Al, ZnO, ZnO+Al blended nanofuels at 60 ppm concentration as shown in Fig. 7.This has been observed due to the following reason that, as load increased, fuel supply has to be increased which leaded to a richer mixture and thus resulted in increasing the CO emissions.

CO emission has been recorded as lower for diesel with nanoparticles (Nanofluid) in contrast to pure diesel [13].

This have been observed because of the following reason that the addition of nanoparticles promoted complete combustion. With the increased concentration of nanoparticles, CO emission have been decreased from 0.04%, 0.04%, 0.055% to 0.025%, 0.028%, 0.035% respectively for Al, ZnO, ZnO+Al blended Nano fuels at 5N-m load.

This has been observed because of improvement in ignition characteristics with Nano fluid additives [4, 14].

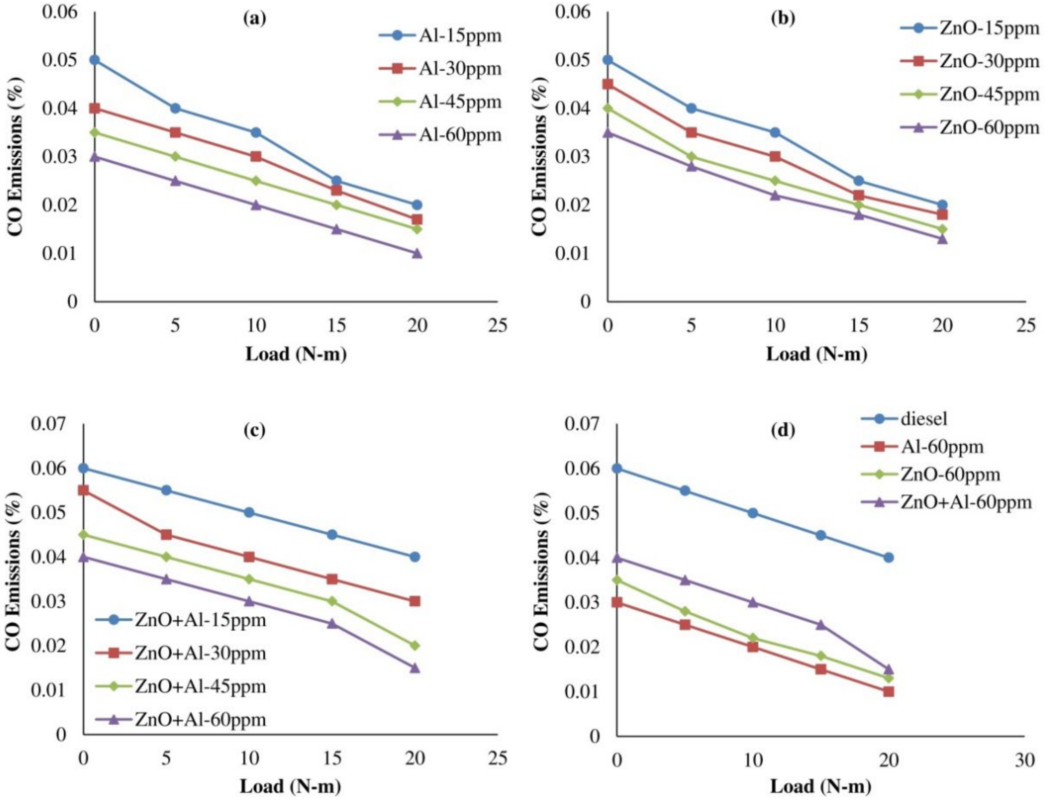

Fig. 7 Variation of CO with Load for different concentration of nanoparticles

4.3.2 Hydro Carbons (HC) Emissions

For aluminum, ZnO and ZnO+Al, Hydro Carbons (HC) emissions increased with load from 13, 14, 16 ppm to 29, 38, 40 ppm respectively at a concentration of 60 ppm, as shown in Fig. 8. Blends gave less HC in contrast to diesel because of its improved combustion inside the combustion chamber because of availability of oxygen atom in Nano additive. Hydrocarbon tends to increase with load due to reduction in oxygen availability when more fuel has been injected.

HC emission have been observed as more for pure diesel than Nano fuels. HC emissions decreased from 42, 66, 46 ppm to 29, 38, 40 ppm respectively for Al, ZnO, ZnO+Al at 20N-m load with increased amount of concentration of nanoparticles in diesel, as it has been observed due to high catalytic oxidation and evaporation rate.

The highest emission has been noted as 66 ppm at 20N-m load for ZnO-15ppm sample while the lowest value recorded for Al-60ppm at 0N-m load as 13ppm [3, 15]. With the addition of metal and metal oxide to diesel, HC reduction has been observed [2, 16-17].

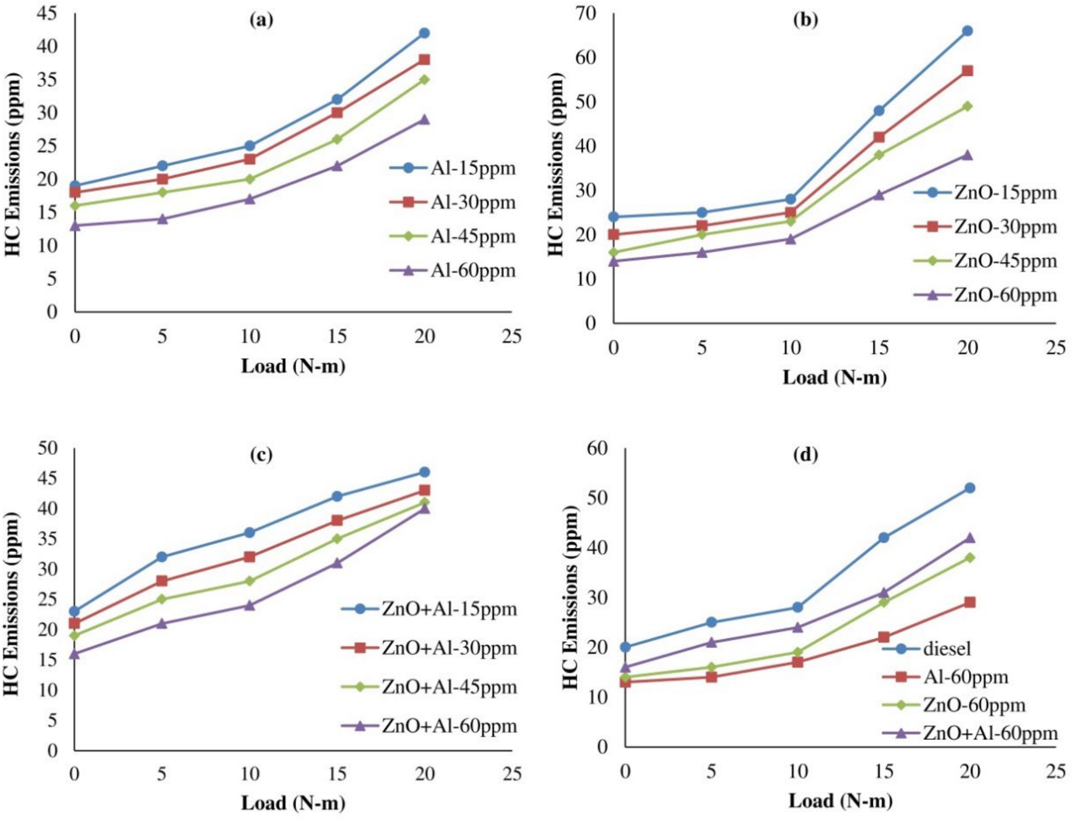

Fig. 8 Variation of HC emissions with Load for different concentration of nanoparticles

4.3.3 Oxides of Nitrogen (NO_x) Emissions

For Al, ZnO and Al + ZnO, NO_x emission increased from a value of 73, 72, 69 ppm to 1035, 1025, 1020 ppm respectively at 60 ppm concentration with the increased load as shown in Fig. 9. It has been observed due to the following reason that with increasing load, average gas temperatures in the combustion chamber increased which resulted in increased of Air-Fuel Ratio. Hence, NO_x emissions reduced.

Emission values increased from 843, 923, 932 ppm to 1035, 1025, 1020 ppm respectively at 20 N-m load with the increased dosage of aluminum, ZnO, ZnO+Al.

Addition of the nanoparticles decreased the temperatures of combustion chamber with high rate of convective heat transfer, with this increase of Nano fraction in fuel leads to reducing the NO_x emission.

There have been observed an increased in NO_x emission when Nano additives are added to pure diesel.

This is due to increased peak temperature. NO_x emission for pure diesel has been recorded as lowest when compared to diesel with nanoparticles [18].

The highest emission has been noted as 1035 ppm at 20 N-m load for Al-60 ppm sample while the lowest has been recorded for ZnO-15 ppm at 0N-m load as 52 ppm.

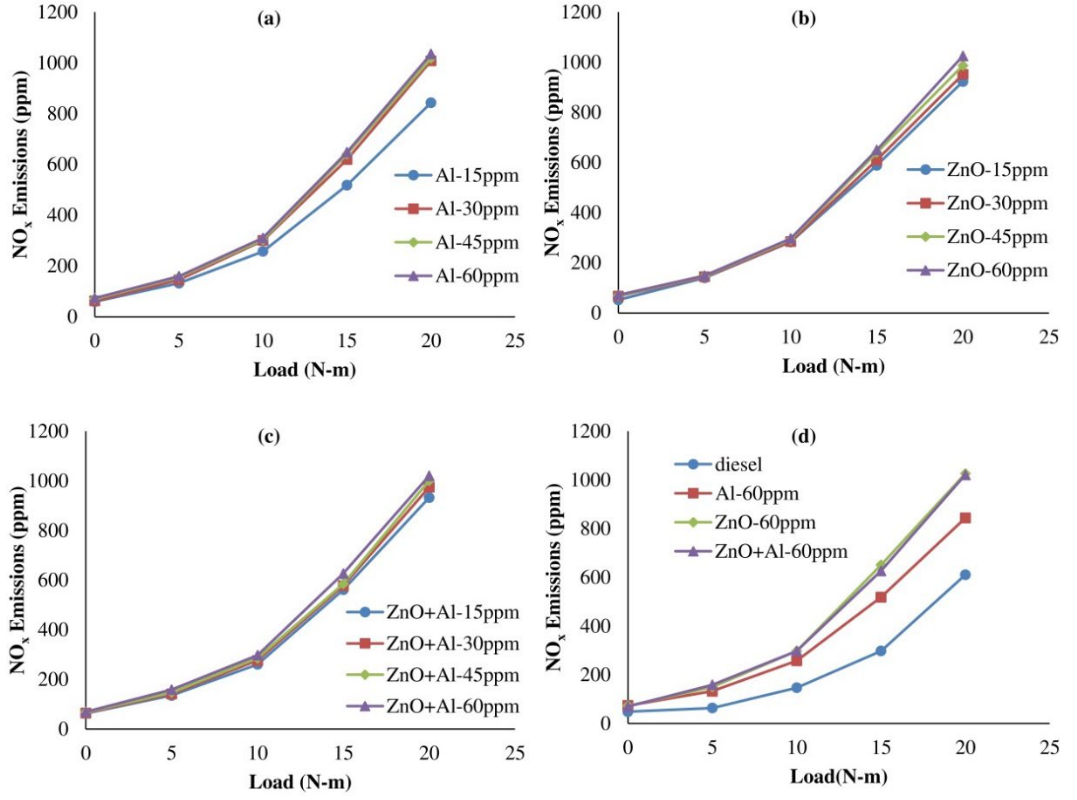

Fig. 9 Variation of NOx emissions with Load for different concentration of nanoparticles

4.3.4 Smoke

For Al, ZnO and Al+ZnO, smoke increased with load this has been observed due to the following reason that the blends serve as an oxidation catalyst which results in lowering of oxidation temperature for Nanofuel soot and lead to raise in particle burn out.

Smoke emission for Al, ZnO and ZnO+Al decreased from 72.5%, 120%, 61.3% to 51%, 49.2%, 51.3% respectively at 20N-m load with increasing number of nanoparticles as shown in Fig. 10.

This has been observed due to the formation of rich mixture which has enhanced the combustion rate at lower loads, smoke values have been recorded as less for Nano fuels than pure diesel.

Most authors noticed that the lower smoke emission has been observed due to higher evaporation rate and ignition delay.

The initial values i.e., at zero load condition, for the concentration of 60 ppm, the values for Al, ZnO, ZnO+Al have been recorded as 5.5%, 4.8%, 7.2% and gradually increased with load and reached to 51%, 49.2% and 51.3% respectively. Lower smoke emissions have been observed [3, 19].

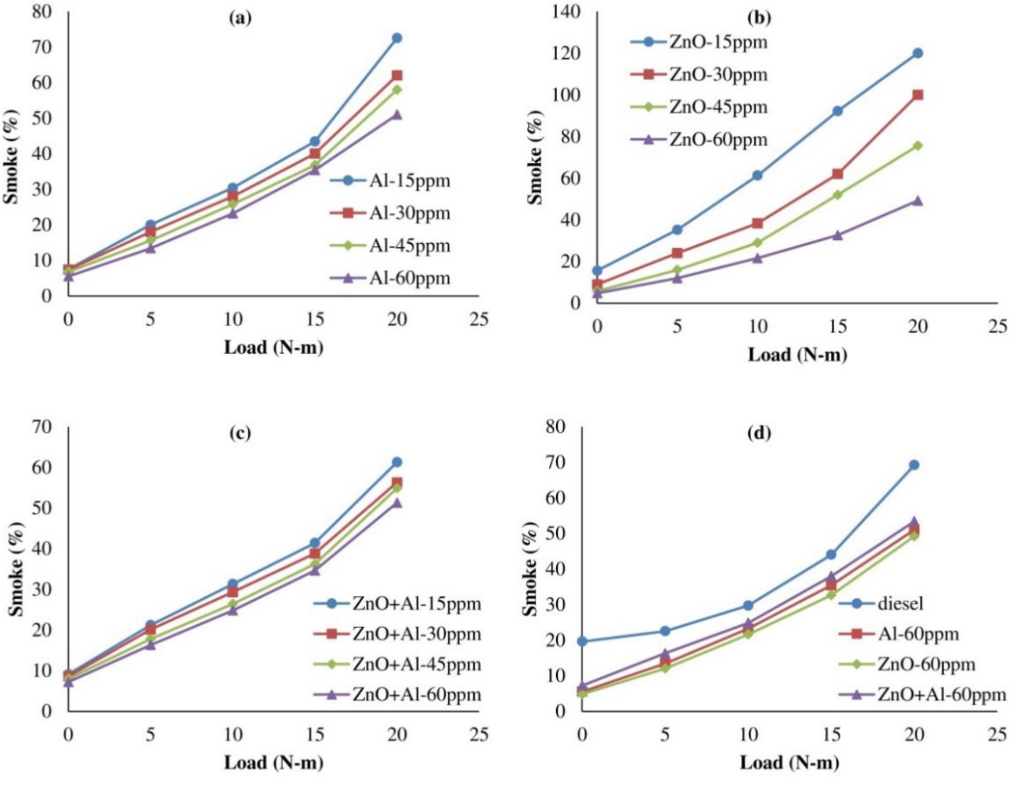

Fig. 10 Variation of smoke emissions with Load for different concentration of nanoparticles

4. CONCLUSIONS

By comparing the previous results to the present work, we have observed mainly four common results which are: Brake Specific Fuel Consumption (BSFC) has reduced as compared to net diesel fuel, Carbon Monoxide (CO) emissions are less for Nano fuels compared to pure diesel, NO_x emissions are slightly higher for Nano fuels and Brake Thermal Efficiency (BTE) values are greater than pure diesel.

From the present work, some of the major conclusions that have been obtained:

- Brake Specific Fuel Consumption (BSFC) decreased with an increase in load and increased in amount of nanoparticles for all the mixtures.
- Brake Thermal Efficiency (BTE) increased with an increase in load and increased in amount of nanoparticles for all the mixtures.
- Cylinder pressure increased with an increase in load.
- As load has increased, Heat Release Rate (HRR) also has increased which can be observed in all samples.
- Ignition delay decreased with an increase in load. There was no major difference observed with an increase in concentration. For all samples, Ignition delay has been slightly lesser than diesel.
- As load increased, Crank Angle 50 (CA50) values also decreased. As concentration increased, CA50 values increased. When compared to diesel, CA50 values have been higher for all samples at all loads.

- Carbon Monoxide (CO) emission has been lower for diesel with nanoparticles (Nano fluid) when compared to pure diesel. And with an increase in load and concentration of nanoparticles in diesel, CO emission decreased.
- For all the mixtures, Hydrocarbons (HC) emission increased with load and decreased with concentration of nanoparticles in diesel. HC emission has been higher for diesel than for the Nanofuels.
- For all the mixtures, Oxides of Nitrogen (NO_x) emission has raised with load. With increased in concentration, NO_x emission increased for all Nano fuels. Also, NO_x emissions of nanofuels are higher than for diesel.
- For all the mixtures, the smoke emission increased with load and decreased with increased amount of concentration of nanoparticles in diesel. Smoke emission has been higher for pure diesel than in case of Nano fuels.

For further research, these nanoparticles can be added to biodiesel and can compare the performance and emission results can be compared by applying various loads. Also, we can use silver metal nanoparticle, carbon nanotube (CNT) as nano additive to both diesel and biodiesel fuels and we can compare their results.

REFERENCES

[1] Chiranjeeva Rao Seela, B. Ravisankar, B. M. V. A. Raju, A GRNN based framework to test the influence of Nano zinc additive biodiesel blends on CI engine performance and emissions, *Egyptian Journal of Petroleum*, vol. **27**, pp. 641-647, 2018.
[2] B. Ashok, K. Nanthagopal, Aravind Mohan, Ajith Johny, A. Tamilarasu, Comparative analysis on the effect of zinc oxide and ethanox as additives with biodiesel in CI engine, *Energy*, vol. **140**, pp. 352-364, 2017.
[3] V. W. Khond, V. M. Kriplani, Effect of Nano fluid additives on performances and emissions of emulsified diesel and biodiesel fueled stationary CI engine: A comprehensive review, *Renewable and Sustainable Energy Reviews*, vol. **59**, pp. 1338-1348, 2016.
[4] R. N. Mehta, M. Chakraborty, P. A. Parikh, Impact of hydrogen generated by splitting water with Nano-silicon and Nano-aluminum on diesel engine performance, *International Journal of Hydrogen energy*, vol. **39**, pp. 8098-8105, 2014.
[5] S. Vellaiyan, K. S. Amirthagadeswaran, The role of water-in-diesel emulsion and its additives on diesel engine performance and emission levels: A retrospective review, *Alexandria Engineering Journal*, vol. **55**, pp. 2463-2472, 2016.
[6] Mu-Jung Kao, Chen-Ching Ting, Bai-Fu Lin and Tsing-Tshih Tsung, Aqueous aluminum Nano fluid combustion in diesel fuel, *Journal of Testing and Evaluation*, vol. **36**, 2007.
[7] S. Kumar, P. Dinesha, Experimental investigation of the effects of nanoparticles as an additive in diesel and biodiesel fuelled engines:a review, *Biofuels*, vol. **10**, pp. 615-622, 2017.
[8] S. Javed, Y. V. V. Satyanarayana Murthy, M. R. S. Satyanarayana, R. Rajeswara Reddy, K. Rajagopal, Effect of a zinc oxide nanoparticle fuel additive on the emission reduction of a hydrogen dual-fuelled engine with jatropha methyl ester biodiesel blends, *Journal of Cleaner Production*, vol. **137**, pp. 490-506, 2016.
[9] Q. Wu, X. Xie, Y. Wang, T. Roskilly, Effect of carbon coated aluminum nanoparticles as additive to biodiesel-diesel blends on performance and emission characteristics of diesel engine, *Applied Energy*, vol. **221**, pp. 597-604, 2018.
[10] T. Shaafi, K. Sairam, A. Gopinath, G. Kumaresan, R. Velraj, Effect of dispersion of various Nano additives on the performance and emission characteristics of a CI engine fuelled with diesel, biodiesel and blends - A review, *Renewable and Sustainable Energy Reviews*, vol. **49**, pp. 563-573, 2015.
[11] V. Praveena, S. Venkatesan and T. Gupta, Effects of Nano additives with biodiesel fuels in internal combustion engines – A Review,*IOP Conf. Series: Materials Science and Engineering*, vol. **402**, 012208, 2018.
[12] Kanagaraj Subramani, Reduction of Emission in a diesel Engine Using Nanofuel - Ceria Nanoparticle Dispersed Diesel, *Journal of ASTM International*, vol. **9**, 10424, 2012.
[13] B. Prabakaran, A. Udhoji, Experimental investigation into effects of addition of zinc oxide on performance, combustion and emission characteristics of diesel-biodiesel-ethanol blends in CI engine, *Alexandria Engineering Journal*, vol. **55**, pp. 3355-3362, 2016.

[14] V. Saxena, N. Kumar and V. K. Saxena, A comprehensive review on combustion and stability aspects of metal nanoparticles and its additive effect on diesel and biodiesel fuelled C.I. engine, *Renewable and Sustainable Energy Reviews*, vol. **70**, pp. 563-588, 2017.
[15] K. Nanthagopal, B. Ashok, A. Tamilarasu, A. Johny, A. Mohan, Influence on the effect of zinc oxide and titanium dioxide nanoparticles as an additive with Calophyllum inophyllum methyl ester in a CI engine, *Energy Conversion and Management*, vol. **146**, pp. 8-19, 2017.
[16] B. Ghobadian, Gholamhassan Najafi, Effect of Nano-particles on the performance and emission of a diesel engine using biodiesel-diesel blend, *International Journal of Automotive and Mechanical Engineering*, vol. **12**, pp. 3097-3108, 2015.
[17] B. Prabakaran, P. Vijayabalan, Influence of zinc oxide Nano particles on performance, combustion and emission characteristics of butanol-diesel-ethanol blends in DI CI engine, *IOP Conf. Series: Materials Science and Engineering*, vol. **377**, 012069, 2018.
[18] Q. Wu, X. Xie, Y. Wang, T. Roskilly, Experimental investigations on diesel engine performance and emissions using biodiesel adding with carbon coated aluminum nanoparticles, *Energy Procedia*, vol. **142**, pp. 3603-3608, 2017.
[19] M. Ghanbari, G. Najafi, B. Ghobadian, T. Yusaf, A. P. Carlucci, M. Kiani Deh Kiani, Performance and emission characteristics of a CI engine using Nano particles additives in biodiesel-diesel blends and modeling with GP approach, *Fuel*, vol. **202**, pp. 699-716, 2017.