

# Performance and emission characteristics of CI engine using diesel and biodiesel blends with nanoparticles as additive - A review study

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**Abstract** - Diesel engine play important role in the field of commercial transportation and agricultural machinery on account of its superior fuel efficiency. Due to shortage of diesel fuel and its increasing cost as well as hazardous emission emitted by diesel engine, the use of biodiesel and its blends has gained importance over the past two decades due to its environmental and economic benefits. Based on results available in literature the use of biodiesel and its blends with diesel improve diesel engine performance and reduce emissions. There exists scope for performance improvement and emission reduction with diesel, biodiesel as base fuel with nanoparticle as additive. In this review paper work has been done to demonstrate the effect of various nanoparticles added diesel and biodiesel on performance and emission characteristics of CI engine.

**Index Terms** - Diesel engine, Biodiesel, Nanoparticles, Performance, Emission.

## I. INTRODUCTION

A diesel engine has an excellent reputation for its low fuel consumption, reliability and durability characteristics because of its higher brake thermal efficiency due to its high compression ratio and leaner fuel-air mixture. On the other hand diesel engine becomes the main air pollution source in the near future due to its combustion products. Polluted air leads to climate changes and affects plants, animals and human alike. Due to rapid growth of automobiles the demand for petroleum products raises day by day which is expected to rise to more than 240 million metric tonnes by 2021-22, which will further increase to around 465 million metric tonnes by 2031-32. However, the rapid depletion of petroleum products and the stringent regulations lay down by the government to engine manufacturers and consumers to follow the emission norms to save the environment from diesel engine pollution have triggered many researchers to identify renewable alternative fuels for diesel engine performance and good emission control [1]. In this regard, biodiesel derived from various vegetable oils such as karanja, jatropha, soybean, palm, neem etc. considered as potential alternative fuel for diesel engine.

The direct usage of vegetable oil in diesel engine is restricted because of their high viscosity, poor atomization, incomplete combustion and carbon deposition on the fuel injectors. The use vegetable oil in lower blend concentration with diesel results in engine performance and emission close to neat diesel, but with higher blend concentration performance and emission much inferior compare to neat diesel because of increase in viscosity [2, 3]. The viscosity of vegetable oil reduced by the process of transesterification by converting vegetable oil into methyl ester or ethyl ester known as biodiesel. The considerable work has been carried out by many researchers on performance and emission characteristics of diesel engine with biodiesel and its blends and showed significant improvement in engine performance and reduction in emission of CO, HC and smoke, but NO<sub>x</sub> emission was higher with biodiesel and its blends because of their higher oxygen content [4-7]. The recent advance in nanotechnology gives the way to produce energetic nanoparticles. The addition nanoadditives in base fuel improve thermo physical properties of fuel such as high surface area to volume, thermal conductivity and mass diffusivity. The use of nanoparticles as additive will act as liquid fuel catalyst and there by enhance the combustion characteristics of engine which will improve engine performance and reduce emissions.

## II. NANOPARTICLES: ITS TYPES AND REQUIREMENTS

Nano-additives are considered as a propitious fuel-borne catalyst to improve the fuel properties, owing to their enhanced surface area/volume ratio, quick evaporation and shorter ignition delay characteristics. The size of nanoparticles varies from 1 to 100 nm [1]. Following are the main requirements of nanoparticles as fuel additive:

1. The nanoparticles act as catalyst should reduce exhaust emission as well as increase the oxidation intensity in the engine and in the particulates filters.
2. It should maintain the typical operational properties of engine.
3. The stability of additive in the fuel must be retained under all operational condition.

The type of nanoparticles is given in table1.

**Table 1 Type of Nanoparticles for IC engine application**

SR. NO.	TYPE	EXAMPLE
1	Metal based nanoparticles	Aluminum, iron, boron and ferric chloride
2	Metal oxide nanoparticles	Cerium oxide, alumina, TiO <sub>2</sub> , MnO, CuO
3	Magnetic nanofluid particles	Fe <sub>3</sub> O <sub>4</sub>
4	Carbon nanotube particles	Single walled and multi walled CNT

### III. COMBUSTION MECHANISM OF NANOPARTICLES ADDED FUELS

Combustion of nanoparticles added fuel occurred in five stages: (i) preheating and ignition stage (ii) classical droplet combustion stage (iii) microEXPLOSION STAGE (IV) SURFACTANT flame stage (v) nanoparticle droplet flame stage [8]. In preheating and ignition stage, evaporation of base fuel occurred on the droplet surface and vapor cloud formed surrounding the fuel droplet. The droplet combustion stage is similar to classical burning behavior of single component droplet. In this stage distinct flame envelope formed around the primary droplet and also small amount of nanoparticles ignited and burning nanoparticles rose quickly to form multiple flares which lead to flame disruption. During flame disruption small bubbles are formed inside primary fuel droplets. These bubbles grow in size and eventually merged into single bubble. Formation of bubbles inside primary droplets builds up intense pressure inside primary drop. Due to building up of intense pressure primary fuel droplets swelled and eventually exploded into smaller droplets and nanoparticles aggregates which ignited and burned forming local flames. This phenomenon of sudden fragmentation of primary fuel droplet into smaller droplets is known as micro explosion. This phenomenon of microexplosion first explained by law [9] based on diffusion-limit model. The droplet surface becomes more concentrated with the less volatile, high-boiling-point component, and the droplet interior has a higher concentration of the more volatile, low-boiling-point component. The latter can be heated beyond its local boiling point, leading to an onset of homogenous nucleation and intense internal pressure buildup and thereby causes fragmentation of the primary fuel droplet. At the end of microexplosion stage nearly all liquid fuel consumed and flame become weaker and finally extinguished and leaving behind agglomerates coated with un-burnt nanoparticles. At the end of microexplosion stage, second flame appear around nanoparticles due combustion of surfactant. This stage known as surfactant flame stage and exists only if fuel droplet contain surfactant. The extinction of surfactant flame is followed by ignition of nanoparticles known as nanoparticle droplet flame stage. In this stage oxygen diffuse on the surface of nanoparticles causes oxidation of nanoparticles. Shortly after nanoparticles are ignited. H. tyagi et al. [10] conducted hot plate ignition probability tests to examine ignition properties of aluminium and aluminium oxide nanoparticles added diesel fuel. They concluded that addition of nanoparticles to fuel improve heat transfer properties and hence droplet ignited at much lower TEMPERATURE THAN PURE DIESEL. Nanoparticles added fuel shows shortened ignition delay, longer flame sustenance, rapid oxidation and hence complete combustion.

### IV. REVIEW OF VARIOUS LITERATURES

In this section review of various literatures has been presented on effects of adding various nanoadditives in base fuel on performance and emission characteristics of diesel engine.

#### A. Effects of metal based nanoadditives on performance and emission characteristics of CI engine

Metal based nanoadditives are used as combustion catalyst to promote complete combustion and to reduce consumption of fuel and emission for hydrocarbon fuels. Metal based nanoadditives reduce diesel emission in two ways: (i) metals react with water vapor in the exhaust emission to produce highly reactive hydroxyl radicals (ii) metal serve as an oxidation catalyst which oxidize CO into CO<sub>2</sub>, HC into CO<sub>2</sub> and water vapor and carbon (soot) into CO<sub>2</sub>. The commonly used metal nanoadditives for hydrocarbon fuels are aluminium, iron, boron and ferric chloride.

**G.R. Kannan et al. [11]** examined effects of 20 µmol/L ferric chloride (FeCl<sub>3</sub>) added to waste cooking palm oil biodiesel on combustion, performance and emission characteristics of single cylinder direct injection CI engine operated at constant speed of 1500 rpm at different operating conditions. The test results showed that the FeCl<sub>3</sub> added biodiesel resulted in decreased brake specific fuel consumption by 8.6% while brake thermal efficiency increased by 6.3% at optimized operating condition of 280 bar injection pressure and 25.5°bTDC injection timing. The FeCl<sub>3</sub> added biodiesel showed lower nitric oxide emission (NO) and slightly higher carbon dioxide emission (CO<sub>2</sub>) as compared to diesel at standard operating condition. Carbon monoxide (CO), total hydrocarbon (THC) and smoke emission of FeCl<sub>3</sub> added biodiesel decreased by 52.6%, 26.6% and 6.9% respectively compared to biodiesel without FeCl<sub>3</sub> at an optimized operating condition, but NO emission slightly increased by 4.1% with FeCl<sub>3</sub> added biodiesel compared to without FeCl<sub>3</sub> added biodiesel at optimum operating condition because FeCl<sub>3</sub> present in fuel oxidize nitrogen into nitric oxide during combustion process. At optimum operating condition higher cylinder pressure, heat release rate and shorter ignition delay period was observed with FeCl<sub>3</sub> added biodiesel.

**Rakhi N. Mehta et al. [12]** investigated burning characteristics, engine performance and emission parameters of a single cylinder CI engine using nanofuels which were formulated by adding nanoparticles of aluminium (A<sub>1</sub>), iron (F<sub>1</sub>) and boron (B<sub>1</sub>) in base diesel. These fuels showed reduced ignition delay and improved combustion rates. The brake thermal efficiency increased by 9%, 4% and 2% for A<sub>1</sub>, F<sub>1</sub> and B<sub>1</sub> respectively as compared to diesel at maximum loading conditions. At higher load the SFC reduced by 7% when engine fuelled with A<sub>1</sub> as compared to diesel, while SFC for F<sub>1</sub> and B<sub>1</sub> was almost same to that of diesel. Volumetric reduction of 25-40% in CO emission, 8% and 4% in hydrocarbon emission was observed when engine fuelled with A<sub>1</sub> and F<sub>1</sub> respectively as compared to diesel. The NO<sub>x</sub> emission marginally increased compare to pure diesel because of increase in burning temperature in the combustion chamber.

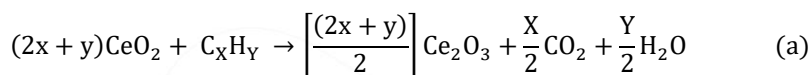
### B. Effects of metal oxide nanoadditives on performance and emission characteristics of CI engine

The metal oxide nanoadditives used for hydrocarbon fuels are TiO<sub>2</sub>, ZnO, MnO, Al<sub>2</sub>O<sub>3</sub> and CuO. The metal based nanoadditives act as oxygen donating catalyst which provide oxygen for oxidation of CO or absorbs oxygen for the reduction of NO<sub>x</sub>.

**V. Arul Mozhi Selvan et al. [13]** evaluated performance and emission characteristics of CI engine by using 25 ppm cerium oxide (CeO<sub>2</sub>) nanoparticles as additive in neat diesel and diesel-methyl ester of castor oil-ethanol blends (D70B10E20). The authors found that the SFC was lower and BTE was higher with addition of CeO<sub>2</sub> in diesel and D70B10E20 blend compare to diesel and D70B10E20 blend. The addition of CeO<sub>2</sub> in diesel and D70B10E20 blend lower emission of CO, HC and smoke, while marginally increased NO<sub>x</sub> emission compare to pure diesel and D70B10E20 blend.

**V. Sajith et al. [14]** carried out experimental investigation on performance and emission characteristics of single cylinder constant speed diesel engine fuelled with CeO<sub>2</sub> nanoparticles (10 to 20 nm) added to jatropa biodiesel with dosing level of CeO<sub>2</sub> vary from 20 to 80 ppm. The tests results showed that BTE increased and SFC reduced by adding nanoparticles in biodiesel compare to pure biodiesel. The nanoadditives promote longer and more complete combustion compared to base fuel because CeO<sub>2</sub> act as an oxygen buffer and thus increase efficiency. Also CeO<sub>2</sub> oxidize carbon deposits from the engine leading to efficient operation and reduced fuel consumption. The addition of CeO<sub>2</sub> nanoparticles to biodiesel decreased CO, HC and soot emission compare to biodiesel without CeO<sub>2</sub>. CeO<sub>2</sub> nanoadditive has the ability to undergo transformation from stoichiometric CeO<sub>2</sub> (+4) valence state to Ce<sub>2</sub>O<sub>3</sub> (+3) (cerous oxide) via relatively low energy reaction. CeO<sub>2</sub> supplies oxygen for the reduction of HC as well as soot and converted to Ce<sub>2</sub>O<sub>3</sub> as per following reactions (a) and (b).

Hydrocarbon combustion:



Soot burning:



The average reduction in HC emission with CeO<sub>2</sub> nanoadditive was 25 to 40 % with dosing level vary from 40 to 80 ppm. Ce<sub>2</sub>O<sub>3</sub> formed from the oxidation of HC and soot remains active and reoxidised to CeO<sub>2</sub> through the reduction of NO as per reaction (c). Hence emission of NO reduced with an average reduction of 30% with dosing level of 80 ppm CeO<sub>2</sub> nanoparticles.



**M.A. Lenin et al. [15]** carried out comparative study on performance and emission characteristics of diesel engine fuelled with 100 mg/L manganese oxide (MnO) and copper oxide (CuO) nanoparticles added in diesel fuel. The brake thermal efficiency of diesel+MnO fuel was higher compare to diesel+CuO and neat diesel for all loads. The brake thermal efficiency for neat diesel and diesel+CuO fuel was nearly same. The emission of CO and NO<sub>x</sub> for diesel+MnO fuel was lower compare to neat diesel and diesel+CuO fuel for all loads. The emission HC for neat diesel, diesel+CuO and diesel+MnO fuels was nearly same for all load conditions.

**M. Santhanamuthu et al. [16]** evaluated performance and emission characteristics of single cylinder CI engine fuelled with polanga oil and diesel blend with iron oxide nanoparticles doped as additive. The BTE and BSEC for POD-iron oxide nanoparticle blends were on par with that of neat diesel. The CO emission was within the range of ±5% of diesel up to 65% load condition and higher beyond 65% load condition for POD-iron oxide nanoparticle blends and HC emission was lesser than neat diesel by 10-20% for POD-iron oxide nanoparticle blends. NO<sub>x</sub> emission was lower for POD-iron oxide nanoparticle blends above 80% load and smoke emission for POD-iron oxide nanoparticle blends reduced by 10-15% to that of neat diesel up to 80% load condition.

**T. Shaafi et al. [17]** showed the influence of alumina nanoparticles, ethanol and isopropanol blend as additive with diesel-soybean biodiesel blend fuel on combustion, performance and emission characteristics of naturally aspirated diesel engine and results were compared with those of neat diesel. Cylinder pressure and heat release rate were higher with D80SBD15E4S1+alumina fuel blend compare to diesel and B20 fuel at higher load condition. The thermal efficiency increased by 15.8% and 17.9% at full load in case of B20 and D80SBD15E4S1+alumina fuel blend respectively compare to pure diesel. The BSFC reduced by 10.60% and 11.46% at full load, when engine was fuelled with B20 and D80SBD15E4S1+alumina fuel blend respectively compare to that of pure diesel. The emission of CO and UBHC reduced, while NO<sub>x</sub> emission slightly increased in case of D80SBD15E4S1+alumina fuel blend compare to diesel and B20 fuel.

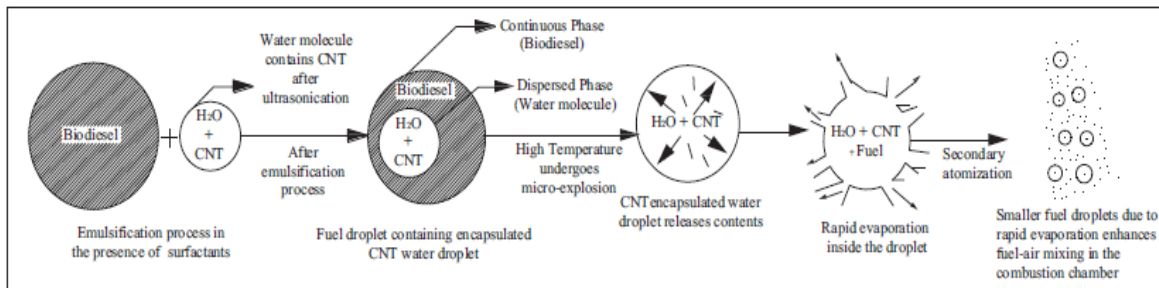
**C. Syed Aalam et al. [18]** conducted experimental investigation to evaluate performance, emission and combustion characteristics of single cylinder CRDI system assisted diesel engine using blend of diesel and zizipus jujube methyl ester blended fuel (ZJME25) along with aluminium oxide nanoparticles (AONP) in mass fraction of 25 ppm and 50 ppm. There was reduction in BSFC with AONP added ZJME25 fuel compare to diesel and ZJME fuel with maximum reduction of 6% observed with 50 ppm AONP concentration ZJME fuel. The brake thermal efficiency increased in comparison with diesel fuel with maximum improvement of 2.5% with 50 ppm AONP concentrated ZJME fuel. Smoke emission reduced by about 15-20% with AONP added ZJME fuel. The HC and CO emission significantly reduced, while NO<sub>x</sub> emission slightly increased. The heat release rate and cylinder pressure increased with the addition of AONP to biodiesel.

**Prabhu L et al. [19]** conducted experiment to investigate performance and emission characteristics of CI engine fuelled with blend of diesel and neem oil methyl ester (B20) along with 250 ppm and 500 ppm TiO<sub>2</sub> nanoparticles. The authors reported that brake thermal efficiency increased and brake specific fuel consumption decreased with TiO<sub>2</sub> added biodiesel blend compare pure diesel and biodiesel blend. The emission of CO, HC and smoke reduced, while NO emission slightly increased with TiO<sub>2</sub> added biodiesel blend compare pure diesel and biodiesel blend.

C. Syed Aalam et al. [20] investigated effects of 40 ppm and 80 ppm  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$  nanoparticles added 20% mahua oil methyl ester blend with diesel (MME20) on performance, emission and combustion characteristics of CRDI diesel engine. They reported that specific fuel consumption decreased and brake thermal efficiency increased with  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$  nanoparticles added MME20 compare to pure diesel and MME20 with higher reduction in SFC and increment in BTE was with  $\text{Al}_2\text{O}_3$  nanoparticle added MME20. Emission of CO, HC and smoke reduced with  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$  nanoparticles added MME20 compare to pure diesel and MME20 with higher reduction in emission was with  $\text{Al}_2\text{O}_3$  nanoparticle added MME20. But  $\text{NO}_x$  emission was higher for  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$  nanoparticles added MME20 compare to pure diesel and MME20. Higher cylinder pressure and heat release rate observed for  $\text{Al}_2\text{O}_3$  nanoparticle added MME20.

### C. Effects of carbon nanotube additive on performance and emission characteristics of CI engine

Carbon nanotubes are wonder material of 21<sup>st</sup> century. J. Sathik Basha et al. [21] carried out experimental investigation to establish the effects of Carbon Nanotubes (CNT) with the Jatropha Methyl Esters (JME) emulsion fuel on performance, emission and combustion characteristics of a single cylinder constant speed diesel engine. The experimental results showed significant enhancement in the brake thermal efficiency for the CNT blended JME emulsion fuels compare to that of neat JME and JME emulsion fuel. At the full load, the brake thermal efficiency for the JME fuel was 24.80%, whereas it was 26.34% and 28.45% for the JME2S5W (93% Jatropha Methyl Esters + 2% Surfactant + 5% Water) and JME2S5W100CNT (93% Jatropha Methyl Esters + 2% Surfactant + 5% Water + 100 ppm CNT) fuels respectively. Increase in brake thermal efficiency with CNT blended JME emulsion fuel is due to combined effect of micro explosion and secondary atomization (Fig. 1) which improve combustion rate.



**Fig 1 Micro-explosion phenomenon of CNT blended JME emulsion fuel [18]**

There was reduction in brake specific fuel consumption (BSFC) with CNT blended JME emulsion fuel compare to that of JME2S5W. At full load BSFC for JME2S5W fuel was 0.346 kg/kW h, whereas it was 0.315, 0.308 and 0.301 kg/kW h for the JME2S5W25CNT, JME2S5W50CNT and JME2S5W100CNT fuels respectively. There was a significant reduction in the peak cylinder pressure and heat release rate for CNT blended JME emulsion fuels when compare to that of neat JME emulsion fuel. At full load, the cylinder gas pressure was 72.3 bar for neat JME fuel, whereas it was 79.77, 76.21, 74.11 and 72.15 bar for the JME2S5W, JME2S5W25CNT, JME2S5W50CNT and JME2S5W100CNT fuels respectively. There was also significant reduction in the level of harmful pollutants in the exhaust gases with CNT blended JME emulsion fuel compare to that of neat JME fuel because of micro explosion and secondary atomization. At the full load, the magnitude of  $\text{NO}_x$  and smoke opacity for the neat JME was 1282 ppm and 69%, whereas it was 910 ppm and 49% for the JME2S5W100CNT fuel respectively. Author concluded that CNT blended emulsion fuel has potential advantage of improving engine performance and reducing emissions.

### D. Effects of organic nanoadditives on performance and emission characteristics of CI engine

The research work on organic nanoadditive in the field of CI engine is limited. W.M. Yang et al. [22] evaluated performance and emission characteristics of 4 cylinder diesel engine fuelled with emulsion fuel with 82.4% diesel, 4% water and 12.6% nano-organic additives by volume. The brake thermal efficiency of engine was 5% higher than pure diesel because of micro-explosion of water droplet contained in emulsion fuel and there was slight reduction in brake power with emulsion fuel compare to diesel because of lower heating value. The BSFC of emulsion fuel was higher than that of diesel fuel. There was also slight reduction in BMEP and IMEP with emulsion fuel. The  $\text{NO}_x$  and smoke emission significantly reduced with emulsion fuel compare to that of diesel. There was reduction in HC and CO emission with emulsion fuel compare to pure diesel. The ignition delay of emulsion fuel was slightly longer than that of pure diesel.

### E. Effects of magnetic nanofluid additives on performance and emission characteristics of CI engine

Magnetic nanofluids are colloidal suspension of magnetic material in liquid medium and they respond to external magnetic field. The most important feature of magnetic nanofluid is their stability which means that particles in the fluid do not agglomerate and phase separate even in the presence of strong magnetic field.

Nasrin Sabet Sarvestany et al. [23] examined the effects  $\text{Fe}_3\text{O}_4$  magnetic nano particles dispersed in the diesel fuel with the concentrations of 0.4 and 0.8 vol% on performance and emission characteristics of diesel engine. The nanofluid fuel with nanoparticle concentration of 0.4 vol% showed better combustion characteristics in comparison with that of 0.8 vol%. There was reduction in BSFC values for 0.4 vol%NF fuel compare to that of neat diesel, whereas 0.8 vol%NF fuel shows an enhancement in BSFC values compared to that of neat diesel and 0.4 vol% fuels. Also experimental results revealed that  $\text{NO}_x$  and  $\text{SO}_2$  emissions reduced, while CO emission and smoke opacity increased with increasing the dosing level of nanoparticles. The  $\text{NO}_x$  emission reduced because iron oxide nanoparticles absorb oxygen for the reduction of  $\text{NO}_x$ , with the average reductions of around 56% and 67% in the cases of 0.4 vol%NF and 0.8vol%NF fuels respectively compare to that of neat diesel. The emission of sulfur dioxide decreased around 14% and 20% in the cases of 0.4 vol%NF and 0.8vol%NF fuels respectively compare to that of neat diesel.

### F. Effects of mixed nanoadditives on performance and emission characteristics of CI engine

**M. Mirzajanzadeh et al. [24]** examined effects of adding hybrid nanocatalyst (CeO<sub>2</sub>+Multi walled carbon nanotube) in diesel and waste cooking oil methyl ester blends (B5 and B20) on performance and emission characteristics of diesel engine. The hybrid nanocatalyst was added in dosing level of 30, 60 and 90 ppm. The engine torque and power increased by adding hybrid nanocatalyst compare to pure blend. The maximum increase in power and torque was 7.81%, 4.91% respectively with B20 (90 ppm) compare to B20. The BSFC reduced by adding nanocatalyst in blend with maximum reduction of 4.50% with B20 (90 ppm) compare to B20. Because of unique oxygen absorption and donation properties of CeO<sub>2</sub> nanoadditive the emission of CO, HC, NO<sub>x</sub> and soot reduced. The MWCNT acts as support for CeO<sub>2</sub>. The maximum reduction in CO, HC, NO<sub>x</sub> and soot were 18.9%, 38.8%, 71.4% and 26.3%, respectively with B20 (90 ppm) compare to neat B20. The MWCNT acts as catalyst to accelerate burning rate which result in decreased ignition delay. The CeO<sub>2</sub> nanoparticles act as oxygen donating catalyst which oxidize CO into CO<sub>2</sub> and absorb oxygen for reduction of NO<sub>x</sub> into nitrogen. The activation energy of CeO<sub>2</sub> burn off carbon deposits within the combustion chamber and hence lower HC and soot emission.

**V. Selvan et al [25]** studied performance and emission characteristics of VCR engine at optimum compression ration of 19:1 using diesterol (diesel-castor oil biodiesel – ethanol blend) - CeO<sub>2</sub>– CNT blends. They used CeO<sub>2</sub> and CNT of each 25, 50 and 100 ppm of concentrations added with diesterol blends. The addition of nanoparticles in diesterol blends increased thermal efficiency by 7.5%, reduced HC and smoke emission by 7.2% and 47.6% respectively compare to diesterol blends without nanoparticles.

### V. CONCLUSION

From the above literature review it has been concluded that

1. The nanoadditives act as combustion catalyst which reduce delay period and promote complete combustion when added to base fuel and hence increase efficiency of engine and lower brake specific fuel consumption.
2. There is reduction in CO emission with all type nanoparticles except magnetic nanoparticles added to base fuel compare to base fuel without nanoparticles because nanoparticles oxidize CO into CO<sub>2</sub>. With magnetic nanoparticles CO emission increase compare to base fuel without nanoparticles.
3. The activation energy of nanoparticles burn off carbon deposits within combustion chamber which lower HC and smoke emission.
4. With nanoparticle added emulsion fuel because of micro-explosion and secondary atomization phenomenon the performance of engine improved and reduced emission compare to emulsion fuel without nanoparticles.
5. Some researchers found that addition of nanoparticles to diesel and biodiesel lower NO<sub>x</sub> emission, while some researchers found that addition of nanoparticles to diesel and biodiesel increase NO<sub>x</sub> emission.

### REFERENCES

- [1] T. Shaafi, K. Sairam, A. Gopinath, G. Kumaresan and R. Velraj, "Effect of dispersion of various nanoadditives 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, May 2015.
- [2] B. De, R. S. Panua, "An experimental study on performance and emission characteristics of vegetable oil blends with diesel in a direct injection variable compression ignition engine", *Procedia Engineering*, vol. 90, pp. 431-438, 2014.
- [3] N. Kapilan, T.P. Ashok Babu and R.P. Reddy, "Improvement of performance of vegetable oil fuelled agricultural diesel engine", *Bulgarian Journal of Agricultural Science*, vol. 15, pp. 610-616, 2009.
- [4] D. Laforgia and V. Ardito, "Biodiesel fuelled IDI engines: performances, emission and heat release investigation", *Bioresource Technology*, vol. 51, pp. 53-59, 1995.
- [5] L.G. Schumacher, S.C. Borgelt, D. Fosseen, W. Goetz and W.G. Hires, "Heavy-duty engine exhaust emission tests using methyl ester soybean oil/diesel fuel blends", *Bioresource Technology*, vol. 57, pp. 31-36, March 1996.
- [6] Raheman and A.G. Phadatare, "Diesel engine emissions and performance from blends of karanja methyl ester and diesel", *Biomass and Bioenergy*, vol. 27, pp. 393-397, March 2004.
- [7] P.K. Sahoo, L.M. Das, M.K.G. Babu, P. Arora, V.P. Singh, N.R. Kumar, T.S. Varyani, "Comparative evaluation of performance and emission characteristics of jatropha, karanja and polanga based biodiesel as fuel in a tractor engine", *Fuel*, vol. 88, pp. 1658-1707, March 2009.
- [8] Yanan Gan, Li Qiao, "Combustion characteristics of fuel droplets with addition of nano and micron-sized aluminum particles", *Combustion and Flame*, vol. 158, pp. 354-368, 2011.
- [9] C. K. Law, "Recent advances in droplet vaporization and combustion", *Progress in Energy and Combustion Science*, vol. 8, pp. 171-201, 1982.
- [10] Himanshu Tyagi, Patrick E. Phelan, Ravi Prasher, Robert Peck, Taewoo Lee, Jose R. Pacheco, and Paul Arentzen, "Increased hot-plate ignition probability for nanoparticle-laden diesel fuel", *Nano Letters*, vol. 8, pp.1410-1416, April 2008.
- [11] G.R. Kannan, R. Karvembu and R. Anand, "Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel", *Applied Energy*, vol. 88, pp. 3694-3703, May 2011.
- [12] Rakhi N. Mehta, Mousumi Chakraborty and Parimal A. Parikh, "Nanofuels: combustion, engine performance and emission", *Fuel*, vol. 120, pp. 91-97, December 2013.
- [13] V. Arul Mozhi Selvan, R.B. Anand and M. Udayakumar, "Effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine", *ARPN Journal of Engineering and Applied Sciences*, vol. 4, pp. 1-6, September 2009.

- [14] Sajith, C.B. Shobhan and G.P. Peterson, "Experimental investigations on the effects of cerium oxide nanoparticles fuel additives on biodiesel", *Advances in Mechanical Engineering*, vol. 36, pp. 1-16, 2010.
- [15] M.A. Lenin, M.R. Swaminathan and G. Kumaresan, "Performance and emission characteristics of a DI diesel engine with a nanofuel additive", *Fuel*, vol. 109, pp. 362-365, March 2013.
- [16] M. Santhanamuthu, S. Chittibabu, T. Tamizharasan, and T.P. Mani, "Evaluation of CI engine performance fuelled by Diesel-Polanga oil blends doped with iron oxide nanoparticles", *International Journal of Chem Tech Research*, vol. 6, pp.1299-1308, June 2014.
- [17] T. Shaafi, R. Velraj, "Influence of alumina nanoparticles, ethanol and isopropanol blend as additive with diesel-soybean biodiesel blend fuel: combustion, engine performance and emissions", *Renewable Energy*, vol. 80, pp. 655-663, March 2015.
- [18] C. Syed Aalam, C.G. Saravanan and M. Kannan, "Experimental investigation on a CRDI system assisted diesel engine fuelled with aluminium oxide nanoparticles blended biodiesel", *Alexandria Engineering Journal*, vol. 54, pp. 351-358, April 2015.
- [19] Prabhu L, S. Satish Kumar, A. Anderson and K. Rajan, "Investigation on performance and emission analysis of TiO<sub>2</sub> nanoparticle as an additive for biodiesel blends", *Journal of Chemical and Pharmaceutical science*, issue 7, pp. 408-412, 2015.
- [20] C. Syed Aalam, C.G. Saravanan, "Performance enhancement of common rail diesel engine using nanoparticles blended biodiesel", *International Research Journal of Engineering and Technology*, 2015, 2, 1400-1410.
- [21] J. Sathik Basha and R.B. Anand, "Performance, emission and combustion characteristics of a diesel engine using carbon nanotubes blended jatropha methyl ester emulsions", *Alexandria Engineering Journal*, vol. 53, pp. 259-273, April 2014.
- [22] W.M. Yang, H. An, S.K. Chou, K.J. Chua, B. Mohan, V. Sivasankaralingam, V. Raman, A. Maghbouli, J. Li, "Impact of emulsion fuel with nano-organic additives on the performance of diesel engine", *Applied Energy*, vol. 112, pp. 1206-1212, 2013.
- [23] Nasrin Sabet Sarvestany, Abdulali Farzad, Ehsan Ebrahimnia-Bajestan and Massoud Mir, "Effects of magnetic nanofluid fuel combustion on the performance and emission characteristics", *Journal of Dispersion Science and Technology*, vol. 35, pp. 1745-1750, July 2014.
- [24] Mehrdad Mirzajanzadeh, Meisam Tabatabaei, Mehdi Ardjmand, Alimorad Rashidi, Barat Ghobadian, Mohammad Barkhi, Mohammad Pazouki, "A novel soluble nano-catalysts in diesel-biodiesel fuel blends to improve diesel engines performance and reduce exhaust emissions", *Fuel*, vol. 139, pp. 374-382, September 2014.
- [25] V. Arul Mozhi Selvan, R.B. Anand, M. Udayakumar, "Effect of cerium oxide nanoparticles and carbon nanotubes as fuel-borne additives in diesterol blends on the performance, combustion and emission characteristics of a variable compression ratio engine", *Fuel*, vol. 130, pp. 160-167, April 2014.