Effects of addition of various nanoparticles on performance and emission properties of compression ignition engine with diesel and biodiesel blends as a fuel – A review study

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ABSTRACT

Due to growth of population, energy consumption, and global warming concerns, design and improvement of high energy efficient and low hazardous emission diesel engines have received substantial attention. In this regard, the various techniques have been employed to improve engine performance such as fuel modification, engine design alteration, and exhaust gas treatment. The purpose of fuel modification is to improve the combustion to obtain low fuel consumption and emissions , using biodiesel and its blends with diesel as a fuel reduces emissions and can be use without engine modification but there is increase in fuel consumption and decrease in brake thermal efficiency. In past few years use of nanoparticles as a fuel additive is emerging owing to its high surface area to volume ratio , oxidation capacity, thermal conductivity when dispersed in any base fuel. It has been found from the literature review that nanoparticles used with diesel ,biodiesel and its blends improves properties of fuel and promote complete combustion which improves performance of the engine as well as reduces exhaust emissions. In this review paper work has been done by detailed study of literatures to examine the effect of various nanoparticles on performance and emission properties of CI engine with diesel ,biodiesel and its blends as a base fuel.

Keyword: *diesel engine, performance, emissions, fuel modification , biodiesel, nanoparticles*.

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1. INTRODUCTION

Diesel engines are receiving more and more attention in transportation, industrial and agricultural sectors because of its reliability and high efficiency due to higher compression ratio and ability to operate at lean fuel-air mixture. On the contrary diesel engines are emerging as one of the major air pollution sources , gases exhausted from diesel engines are responsible for climate changes and greenhouse effect which affects plants, animals and human alike. In addition, new petroleum reserves appear to grow arithmetically while the consumption growing geometrically. Under this situation, when consumption overtakes discovery, the world will be leading to an industrial disaster. Due to the rapid depletion of petroleum products and the strict rules imparted by the government to engine manufacturers and consumers to follow the emission norms to save the environment from diesel engine pollution have obliged many researchers to identify alternative techniques for diesel engine which can improve performance and emission control. Most of the researchers have contributed their efforts to reduce the emissions from the diesel engines in three ways 1) engine design modification 2) fuel adulteration 3) treatment of the exhaust gas.

Fuel modification is widely accepted by researchers in order to achieve specific fuel properties by which engine performance can be improve and emission is reduce without any change in existing engine design. In this regard biodiesel derived from various vegetable oils such as soybean, cotton seed, sunflower , rapeseed , palm , coconut , linseed , karanja , jatropha oil considered as a potential source of alternative fuel for CI engine. Vegetable oils are obtained from renewable sources and they are biodegradable, non toxic, produces less emissions. In addition their

Cetane numbers and calorific values are comparable with those of diesel and they are also compatible with the materials used in distribution of fuel system. They can be used alone or blends with diesel fuels[2] . On the other hand, operation of diesel engines with vegetable oils produces several problems in atomization and injection of fuel from nozzles due to their lower volatility and higher viscosity, molecular weight and density [3]. Vegetable oil was modified through transesterification process to produce biodiesel fuel to improve these properties. Many researchers worked on use of biodiesel and its blends with diesel as a fuel and got considerable improvements in performance and emission reduction ,but it observed higher specific fuel consumption and lower brake thermal efficiency with biodiesel and its blends as a fuel as compared to pure diesel because of lower calorific value of biodiesel. In this regard nanoparticles used as a fuel additives, they acts as a combustion catalyst which reduces ignition delay and heat release rate as well as increases overall efficiency , peak pressure and emissions of CO, HC, CO_2 .

2. NANOPARTICLES AS A FUEL ADDITIVE

Nanoparticles acts as a fuel borne catalyst which improves specific properties of fuel when added to the base fuel depending upon the dosage of it such as, flash point, fire point, kinematic viscosity, heating value and cetane number[1]. this is due to its better thermo physical properties. particles which have size in between 1 nm to 100 nm are consider as a nanoparticles.

Requirements of nanoparticles as a fuel additives

1) It should maintain the operational characteristics of the engine.
2) Addition of nanoparticles must not affect chemical stability of mixture under all conditions.
3) Addition of nanoparticles must reduce the exhaust emission and increase the oxidation intensity of the engine and particulate filters.
4) It should not affect working effectiveness of particulate filters.
5) It should reduce specific fuel consumption and increase thermal efficiency for constant power

2.1 Nanofluid preparation

1) Single step method

This method combine preparation of nanoparticles with synthesis of nanofluid for which nanoparticles are directly prepared by physical vapour deposition (PVD) method or liquid chemical method. In this technique the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized and the stability of fluids is increased. The main limitation of this method is that it is preferred with low vapor pressure fluid.[2]

2) Two step method

In this method preparation of nanofluid isolate from the production of nanoparticles. In first step nanoparticles are produced as dry powder by inert gas condensation, chemical vapor deposition, mechanical alloying or suitable techniques and then nanoparticles are dispersed into base fluid in second step. The stability of nanofluid is increase by ultrasonic bath stabilization or by adding surfactant in the fluid. This method of nanofluid preparation is economic then single step method. This method is most commonly used for the preparation of blend of nanoparticles with diesel and biodiesel.[2]

3. LITERATURE REVIEW

In this section detailed study of various literatures has been carried out and results obtained from literatures presented on effect of various nanoadditives on performance and emission characteristics of diesel engine.

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

Metal nanoparticles such as aluminium, boron, zinc, iron and ferric chloride are used as catalyst in CI engine fuel to promote complete combustion and reduce hydrocarbon and soot emissions by oxidizing HC, CO and particulate matter to CO2 . These nanoaddtives also reduce emission by reacting with water vapor in the exhaust to produce highly reactive hydroxyl radicals. They also reduces specific fuel consumption and improves brake thermal efficiency.

Rakhi N. Mehta , Mousumi Chakraborty et al.[5] investigated burning ,performance and emission characteristics of single-cylinder, four stroke, constant speed (1500 rpm) direct injection diesel engine with addition of nanoparticles of aluminium(A1) , boron(B1) and iron(F1) in base fuel of diesel. The engine tests were performed initially with pure diesel at fully throttled and no-load conditions and then nanofuels were fed one by one through a separate fuel feed line. Combustion results showed that diesel gave first flamed within 1.2 s and flame extincted within 1.5 s where as drops of A1 and F1 not only ignited within 0.2 s but also the flame lasted longer for 1.69 s, this is due to microexplosion phenomena of nanoparticles. SFC was higher for A1 and F1 as compared to diesel at low load, but at high load it was 7% lower for A1 than diesel. Exhaust gas temperatures of A1, F1 and B1 soared by 9%, 7% and 5% respectively, resulting into increase in brake thermal efficiencies by 9%, 4%, and 2% as compared to diesel at maximum load. At same loads, the emission study showed a drop of 25–40% in CO along with a drop of 8% and 4% in hydrocarbon emissions for A1 and F1 nanofuels respectively. Due to higher temperatures NOx emission was increased of 5% and 3% with A1 and F1 respectively than diesel.

G.R. Kannan , R. Karvembu et al.[6] analysed the addition of ferric chloride (FeCl3) as a fuel borne catalyst (FBC) in waste cooking palm oil based biodiesel on combustion ,performance and emission characteristics of a direct injection diesel engine operated at a constant speed of 1500 rpm at different operating conditions. For this purpose ferric chloride added in biodiesel at a dosage of 20 lmol/L. Test results indicate that addition of FBC in biodiesel increase cetane number and calorific value of fuel. The FBC added biodiesel showed a lower BSFC of 0.4 kg/kW h at 220 bar , 23°bTDC and 0.3 kg/kW h at 280 bar, 25.5°bTDC in comparison with biodiesel at the same operating conditions. the brake thermal efficiency increased by 6.3% with FBC added biodiesel. In addition, Carbon monoxide (CO), total hydrocarbon (THC) and smoke emission of FBC added biodiesel decreased by 52.6%, 26.6% and 6.9% respectively and emission of NO and CO2 emission was Increased with FBC added biodiesel. Lastly FBC added biodiesel showed higher cylinder gas pressure, heat release rate and shorter ignition delay at optimized operating conditions.

Mu-Jung Kao,1 Chen-Ching Ting et al.[7] examined effect of aqueous aluminium nanofluid combustion in diesel fuel using a single-cylinder engine. The average diameter of the aluminum nanoparticles is about 40–60 nm and they are covered with thin layers of aluminium oxide due to the high oxidation activity of pure aluminium. The results showed that, hydrogen burns in a diesel engine in the presence of an active aqueous aluminium nanofluid. The results indicate that the brake specific fuel consumption (BSFC) for aqueous aluminium nanofluid mixed diesel fuels (AN+D) is less than that of the diesel fuel at engine speeds less than 1800rpm.The authors concluded that adding a particular quantity of aluminium nanofluid to diesel not only reduces fuel consumption, but also improves the exhaust emission concentration from a diesel engine.

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

Metal oxide nanoparticles such as CeO2, TiO2, ZnO, MnO, Al2O3 and CuO are used as combustion catalyst in diesel engine to reduce emissions and get optimum performance. Metal
Oxide nanoadditives normally acts as a oxidation catalyst as they provide oxygen for oxidation of CO and UHC as well absorbs oxygen for reduction of NOX.

Chiranjeeva Rao Seela , B. Ravisankar et al.[8] investigated the effect of zinc oxide (ZnO) nanoparticles suspensions in diesel and Mahua biodiesel blended fuel on single cylinder diesel engine performance characteristics. The results indicate that ZnO particulate addition yields favourable performance and emission control of the engine. A generalized regression neural network (GRNN) is implemented for predicting the performance and emissions of the engine at various operating conditions based on the experimental results.

V. Arul Mozhi Selvan, R. B. Anand et al.[9] conducted the investigation to evaluate the performance and emission characteristics of a CI engine while using cerium oxide nanoparticles of size 32 nm as additive in neat diesel and diesel-methyl ester of castor oil-ethanol blends (D70B10E20) . In first phase stability of diesel biodiesel – ethanol with cerium oxide analysed and in second phase performance and emission characteristics was checked. Test Results revealed that SFC was lower for cerium oxide added blend D+CERIA25 and it was 0.3586kg/kW.hr which was less than that of 0.3931kg.kW.hr for diesel .BTE was measured highest for neat diesel of 25.66% as compare to 23.63% of D70C10E20 at bmep of 0.44Mpa. With addition of cerium oxide peak pressure increased while ignition delay and heat release rate decreased. CO and HC emission decreased with addition of CeO_2, HC was lowest at 97 ppm with D+CERIA25 blend. The smoke opacity decreases with diesel ethanol blends when comparing with neat diesel. Also the addition of cerium oxide decreased smoke further.

T. Shaafi, R. Velraj et al.[10] evaluated effect of alumina nanoparticles of 50 nm size on performance and emission properties of a single cylinder, naturally aspirated, air cooled, constant speed CI engine, fuelled with two modified fuel blends, B20 (Diesel-soybean biodiesel) and diesel-soybean biodiesel-ethanol blends, with alumina as a nanoadditive (D80SBD15E4S1 +alumina) . BSFC for B20 and D80SBD15E4S1 + alumina is higher than diesel at low load but at high load it is lower as compared to diesel, the presence of the alumina nanoparticle in the D80SBD15E4S1 fuel blend enhances the combustion characteristics, due to the large surface area, and hence, the BSFC is minimum in the case of D80SBD15E4S1 +alumina fuel blend. An increased emission of NOx at 7.2% and 9.9% was observed in the case of B20 and D80SBD15E4S1 + alumina fuel blend respectively. Moreover, there is a considerable reduction in the major pollutants such as CO, CO_2, UBHC in the case of D80SBD15E4S1 þ alumina fuel blend, compared to neat diesel at the full load condition.

M.Santhanamuthu, S.Chittibabu et al. [11] examined the performance and emission characteristics of CI engine fuelled by fuelled by polanga oil diesel fuel blend with iron oxide nanoparticles in proportions of 100,200 and 300 ppm respectively. The engine was loaded at five different brake powers for each polanga oil – diesel – iron oxide nanoparticle fuel blends. test results revealed that Performance of blend of 900 ml diesel, 300 ml polanga oil and 100 ppm nanoparticles was observed to be closer to neat diesel performance at 80% load conditions.in addition higher concentration of iron oxide nanoadditives did not much affects performance and emission properties.

C. Syed Aalam et al.[12] experimented effect of nanoparticles of aluminium oxide (AONP) and iron oxide (IONP) on performance and emission characteristics of single cylinder CRDI diesel engine fuelled with Mahua methyl ester at the ratio of 20% (MME20) with diesel. The nanoparticles added to MME20 in proportions of 40ppm and 80ppm with the help of ultrasonicator and a mechanical homogenizer. Test results showed that AONP blended fuel shows a considerable decrease of SFC in comparison with IONP blended MME20 as fuel. In case of AONP40+MME20 the BTE was increased up to 0.8%, but in the case IONP40+MME20 the BTE was increased upto 4.3% as compare to pure diesel. The CO emission decreased about 17% and 19% in the cases of MME20+IONP40 and MME20+AONP40 fuels, respectively at the full load of the engine. Whereas CO emission was reduced about 18% and 20% for MME20+IONP80 and MME20+AONP80 respectively. The addition of nanoparticles to MME20 observed increased of NOx emission. The smoke emission of MME20 was decreased with the addition of nanoparticles by about 15-18%, at full load.

M.A. Lenin , M.R. Swaminathan et al. [13] evaluated the effect of metal oxide nanoadditives manganese oxide (MnO) and copper oxide (CuO) doped with diesel on a single cylinder, air cooled Direct Injection (DI) diesel engine. Metal oxide additives was prepared by the powder mixing method, and sol–gel method. Two experiments carried out with proportion of 200mg/L of each nanoparticles one by one. Author concluded that Brake thermal efficiency increased marginally by 4% from the conventional diesel fuel with addition of MnO and CuO. Moreover, there was significant reduction was observed in HC, CO and NOx emission with MnO+diesel and CuO+diesel. In addition performance with MnO+diesel was slightly better than CuO+diesel.

K. Fangsuwannarak, K. Triratanasirichai et al. [14] investigated change in properties of palm biodiesel with addition of TiO_2 nanoparticles and accordingly performance and emission characteristics were analysed. nano TiO_2 was added in fraction of 0.1% and 0.2% by volume . Test results revealed that all biodiesel fuel with 0.1% TiO_2 additive obtained the higher level of brake power, wheel power, and engine torque as compared with all biodiesel fuel without 0.1% TiO_2 additive. However, 0.2% additive increases the specific fuel consumption. Moreover

Because of higher carbon combustion activation and hence promoting complete combustion, emission levels of CO, CO2 and NOx are appreciably reduced with the addition of TiO2 nanoparticles.

C. ***Effects of organic nanoadditives on performance and emission characteristics of CI engine***

W.M. Yang , S.K. Chou et al. [15] conducted experiment with emulsion fuel with 82.4% diesel, 5% water and 12.6% nano-organic additives to determine performance and emission properties of A 4-cylinder diesel engine with common rail fuel injection system. The major components of the organic additives include glycerin and polyethoxy-ester which are water soluble oxygenated fuel. The results indicate that a better brake thermal efficiency can be achieved with the emulsion fuel due to the effect of micro-explosion of water droplets. At the same time, NOx emission is reduced because of the presence of water, which brings down the peak flame temperature. It is also found that the ignition delay of emulsion fuel is slightly longer than that of pure diesel, however, the combustion duration is shorter, which further explains why the emulsion fuel can increase the efficiency of the engine.

D. ***Effects of magnetic nanofluid additives on performance and emission characteristics of CI engine***

A ferrofluid (magnetic nanofluid) is a suspension of ferromagnetic nanoparticles inside a carrier liquid such as water or an organic solvent. One of the most important features of ferrofluids is their stability, which means that particles in the fluid do not agglomerate and phase-separate even in the presence of strong magnetic fields.

Nasrin Sabet Sarvestany et al. [16] evaluated the effect of magnetic ferrofluid in performance and emission of CI engine. For this purpose Fe3O4 nanoparticles dispersed in the diesel fuel with the nanoparticle concentrations of 0.4 and 0.8 vol% were employed for combustion in a single-cylinder, direct-injection diesel engine. The results indicated that the nanofluid fuel with nanoparticle concentration of 0.4% shows better combustion characteristics in comparison with the nanoparticle concentration of 0.8%. It means that the selection of the proper dosing of nanoparticles should be considered. The investigation on the exhaust emissions demonstrated that the NOx and SO2 emissions reduce dramatically, while the CO emission and the smoke opacity increase noticeably, with increasing the dosing level of nanoparticles.

E. ***Effects of carbon nanotube additive on performance and emission characteristics of CI engine***

Carbon nanotubes have been called wonder material of 21st century. Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure called graphene cylinder. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Single walled carbon nanotube have single layer of graphene cylinder, while multiwalled carbon nanotube have two or more than two layer of graphene cylinders.

Ghanshyam S. Soni et al. [17] investigated the effect of Multiwalled Carbon Nanotube on performance and emission characteristics of single cylinder, air cooled diesel engine fuelled with diesel and Karanja Methyl Ester blends. The multiwalled carbon nanotubes are blended with diesel and biodiesel in three different proportions of 50mg/lit, 100 mg/lit and 150 mg/lit. experimental results showed that brake thermal efficiency for diesel and biodiesel was 29.13% and 23.30% respectively, where as it was 32.92% and 27.48% for Diesel+MWCNT150 (150 mg/lit MWCNT blended diesel) and KME+MWCNT150 (150 mg/lit MWCNT blended biodiesel) respectively. The HC emission reduced by 23.07% and 27.58% for Diesel+MWCNT150 and KME+MWCNT150 compared to neat biodiesel respectively. There was also reduction in CO emission with a reduction of 35.13% and 38.89% with Diesel+MWCNT150 and KME+MWCNT150 as compared to pure biodiesel respectively at full load. There was slight increase in oxide of nitrogen and carbon dioxide emission with MWCNT blended diesel and biodiesel observed.

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

M. Mirzajanzadeh et al. [18] examined effects of adding mixed nanoparticles (CeO2+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 nano catalyst was added in dosing level of 30, 60 and 90 ppm. 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 nano catalyst in blend with maximum reduction of 4.50% with B20 (90 ppm) compare to B20. Because of unique oxygen absorption and donation properties of CeO2 nanoadditive the emission of CO, HC, NOx and soot reduced. The MWCNT acts as support for CeO2. The maximum reduction in CO, HC, NOx 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 CeO2 nanoparticles act as oxygen donating catalyst which oxidize CO into CO2 and absorb oxygen for reduction of NOx into nitrogen. The activation energy of CeO2 burn off carbon deposits within the combustion chamber and hence lower HC and soot emission.

V. Selvan et al [19] studied performance and emission characteristics of VCR engine at optimum compression ratio of 19:1 using diesterol (diesel-castor oil biodiesel – ethanol blend) - CeO2 – CNT blends. They used CeO2 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.

4. FUTURE RESEARCH REQUIREMENTS

Effect of nanoparticles is yet not explored upto its fullest potential there are various issues related to safety and stability is require to be examined before use it in commercial vehicles. Following consideration can be taken into account for further research in field of nanoparticles in diesel engine.

1) Nanoparticles with different sizes can be used to determine effect of particle size on engine performance and emission.
2) Experiment with nanoparticles in CI engine can be conducted at different compression ratio to identify its effectiveness.
3) Safety criteria for public concern during production and its use are rarely attempted, so work can be done in that direction.
4) Analysis of the combustion and flame characteristics of the catalyst enhanced fuel using visualization techniques should be carried out.

5. CONCLUSION

From the above discussion and literature review it can be concluded that

1) Biodiesel is biodegradable, non-toxic and compatible with diesel. Biodiesel and its blends with diesel reduces total emission and its low concentration in diesel can give similar result as that of pure diesel , so biodiesel can be used as alternative source for diesel engine.
2) 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.
3) The activation energy of nanoparticles burn off carbon deposits within combustion chamber which lower HC and smoke emission.
4) Addition of nanoparticles in base fuel improves certain specific properties of fuel such as cetane number, flash point, fire point and calorific value because of their high surface area to volume ratio, thermal conductivity and mass diffusivity.
5) The CO emission also reduces due to complete combustion of the fuel. Only in the case of fuel with magnetic nanofluid the CO level is increases.
6) Some researchers found that addition of nanoparticles to diesel and biodiesel lower NOx emission, while some researchers found that addition of nanoparticles to diesel and biodiesel increase NOx emission

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