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A review of the performance and emissions of nano additives in diesel fuelled compression ignition-engines

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Abstract. This paper reports the results of various researches on the engine performance and emission characteristics of Diesel engine using nano particles additives in diesel, biodiesel and water emulsified fuels. There are two methods of reducing the exhaust gas emission of the Diesel engine. First method is to reduce the emissions by using exhaust gas treatment devices like catalytic converter and diesel particulate filter. However, use of these devices affects the performance of Diesel engine. Second method to reduce emissions and improve performance of CI engine is the use of fuel additive. Main pollutants of Diesel engine are oxide of nitrogen (NOx) and particulate matter (PM). However, it is difficult to control NOx and PM simultaneously. Many researchers report that the best method to control the emissions and improve the engine performance is the use of nano particles additives and water emulsified fuels. This research paper also reports the biodiesel fuel as an alternative to diesel fuel by using various nano particle additives. Comparative studies of effects on various properties of diesel and biodiesel fuels without/with water contents and nano particles additives by previous researchers are done. Most of the researchers reported improved engine performance and reduction in emission characteristics with dosing of nano particles additives in diesel and biodiesel.

1. Introduction

There is a increasing demand for energy due to the increasing population which can lead to greater air pollution. On the other hand, it is clear that there are limited sources of fossil-based fuels as a sustainable energy. As a result of world industrialization, the demand for oil-based fuels (fossil fuels) has increased dramatically [1–3]. Apart from the economic matters, the widespread use of fossil fuels is responsible for a long-term environmental problem in the form of climate changes and the global warming. The main source of energy in different forms originates from the combustion. Recently, depletion of the fossil fuels due to their continuous use has become the first priority concern for all people in the world whose lives depend on this source of energy for all their activities. Diesel engines have a considerable share of transportation. At the same time, along with the large-scale use of the diesel fuels, lung diseases and cancer invasion have been increased dramatically [4–6], such that a comprehensive study on this issue seems necessary. Today, the fossil fuels constitute about 80% of the total needed energy with almost 50% of it being related to the local transportation [7].

The diesel fuel mainly contains aliphatic hydrocarbons of C8–28 with boiling temperatures varying from 130 to 370 °C [8]. The exhaust emissions from the diesel engines contain various types of air pollutants such as total hydrocarbon content (THC), oxides of nitrogen (NOx), particulate matter

(PM), carbon monoxide (CO). The oxides of nitrogen and sulfur which are emitted by internal combustion engines can result in acid rains [6,7]. When blending the oxygenate fuels with the diesel fuels, the chemical-physical properties of the fuel including flash point, density, viscosity and actually cetane number might be altered. The oxygenate fuels has a low cetane number, flash point, viscosity and density [1–4]. For solving this problem and especially increasing the cetane number, one needs to use tertiary additives which are known as the cetane number improvers. The main and most important tertiary additives available are nitro methane, nitro ethane, 2-methoxy ethyl ether, methyl ester and octyl nitrate. Tertiary additives have high performance improving the cetane number and preventing formation of a two-phase blend. However, the tertiary additives can enhance the flash point, viscosity and density as well. Researcher worked on effect of an alkyl nitrate that is 2-ethyl-hexyl nitrate as a cetane number improver and finally showed that these nitrogenate additives promote the cetane number significantly [9].

Blending of the oxygenated fuels and the tertiary additives causes a poor brake power, but may increase the BSFC on the other hand. For increasing of the brake power, one should use a nano-metal additive. Adding the nano-metal additive to the fuel, thermal conductivity coefficient of the fuel is decreased, so that blending with a metal with lower thermal conductivity would be a promising alternative for improving the brake power. The main potential nano-metal additives are: manganese, cerium, alumina and silica. Researcher worked on the impact of blending cerium oxide and cerium dioxide on the engine performance showed that the BSFC, HC emission and NO_X emissions were decreased by adding the nano additives, but the engine power is enhanced by adding both of the nano additives [10-12]. This enhancement was affected from increasing of the hot spot value in the engine. Other researcher presented a research that used di-ethyl ether as nano additives could increase the engine power [13-15]. This paper reports the results of various researches on the engine performance and emission characteristics of Diesel engine using nano particles additives in diesel, biodiesel and water emulsified fuels.

2. Nano additives for Diesel Engine

Nano particles as a fuel additive in Diesel engine used by researchers and scientists are presented in this section. Nanosize material includes metals like, Al, Mg, Zr, Ti, Ni, boron (a metalloid), and metal oxides [16,36]. Recently, nanosized silicon powders and nanoporous silicon wafers were considered for energetic applications [35]. Basha et al. [21] prepared the samples of alumina nanofluid with concentration of 25, 50 and 100 ppm in 15% water and jatropha biodiesel emulsion fuel as a base fuel and used in Diesel engine. The experiments were conducted at a constant speed of 1500 rpm using nano alumina blended water diesel emulsion fuel with a mass fraction of 25 ppm, 50 ppm and 100 ppm [15]. Fangsuwannarak et al. [17] investigated 0.20% nano TiO_2 in diesel fuel and 5% palm oil and 95% diesel as base fuel .

The nano zinc oxide particles about 5 ppm to about 60 ppm was used by Tock et al. [18]. Karthikeyan et al. [43] studied zinc oxide nano particles of 50 and 100 ppm in blends of diesel–pomoplion stearin wax biodiesel as a base fuel. Sajeevan et al. [19] experimentally investigated nano cerium oxide with concentration of 5–40 ppm on a single cylinder Diesel engine fueled with the diesel and cerium oxide blended diesel. Sajith [20] investigated cerium oxide nanoparticles with dosing level varied from 20 to 80 ppm in a base fuel as a jatropha biodiesel on a single cylinder, WC, 4-stroke Diesel engine. Selvan et al. [27] used 25 ppm cerium oxide nanoparticles as additive in neat diesel and diesel–biodiesel–ethanol blends. Ganesh et al. [22] used nano Cobalt oxide (Co_3O_4) and Magnalium in jatropha biodiesel a base fuel for Diesel engine.

Nano CuO, $CuCl_2$, $CoCl_2$, $FeCl_3$ and $CuSO_4$ can be used as a catalyst for Diesel engine. These metal base additives were used with dosing 5–50 mmol by Kannan et al. [23]. Shafil et al. [24] used ferrofluid (Fe_3O_4) having 0.4% and 0.8% volumetric proportions in diesel and conducted the experiment on fourcylinder, inline, four-stroke, compression ignition, water cooled engine. Sarvestany et al. [44] examined the effect of the magnetic nanofluid fuel (Fe_3O_4) in diesel with concentration of 0.4 and 0.8% by volume on the compression ignition engine. Nanometal oxide of manganese oxide (MnO) and copper oxide (CuO) with dosing 200 mg/l in diesel was used by Lenin et al. [28]. Balamurugan et al. [35] used Soya bean biodiesel with nano-copper particle as a fuel additive with concentration of 1.5%. Basha et al. [42] prepared emulsion of Jatropha methyl ester and carbon nano tube with dosing of 25, 50 and 100 ppm. Selvan et al. [40] investigated mixture of cerium oxide and carbon nano tube additives in diesel– biodiesel–ethanol blend with dosing of 25, 50 and 100 ppm each. The combination of 25 ppm alumina and 25 ppm CNT blended biodiesel were prepared and tested by Basha [25]. Kao et al. [26] used the aluminum nanofluid (AN) additive with concentration varied from 30 cc to 50 cc per liter in diesel. Luman et al. [37] prepared several combinations by dosing nano-sized aluminum particles and ultra-fine boron particles. It was found that the addition of nano-sized aluminum particles can enhance the propellant burning rate.

3. Fuel Properties

3.1 Density, flash point and viscocity

Effect of nano additives on fuel properties are presented here. Density and kinematic viscosity of nanoemulsion fuels increased marginally probably due to the presence of water [41]. No significant effect on properties like density, viscosity and flash point was observed with the addition of zinc nano particles in diesel– pomoplion stearin wax biodiesel blends [43]. Fangsuwannarak and Triratanasirichai [50] prepared the blends of palm oil biodiesel by increasing concentration from 2–100% in diesel and then added nano-TiO2 with dosing concentration of 0.1% and 0.2% by volume and tested the physical properties of fuel samples using ASTM standard procedure.

They observed that kinematic viscosity was reduced by increasing concentration of nano-TiO2 as compared to without additive. However, the calorific value was increased with increasing concentration of additives. Arockiasamy and Anand [52] used 30 ppm cerium oxide and alumina nano particles additive separately in jatropha biodiesel to prepare blend for testing properties and found that slightly increase in viscosity with the addition of both nano particles in jatropha biodiesel. They also observed that reduction in calorific value and flash point as compared to neat biodiesel.

3.2 Cetane number and calorific value

Researches on the effect of nanofluid additives on cetane number and calorific value are presented here. Most of researchers reported that addition of nano particles in diesel and biodiesel improves cetane number and calorific value. Higher cetane indices were obtained for nano aluminum (n-Al) and nano silicon (n-Si) in water–diesel emulsion as compare to diesel which ascertains better combustion quality [41]. The improvement in calorific value and cetane index was observed with the addition of zinc nano particles in diesel-pomoplion stearin wax biodiesel blends [43]. Singh and Bharj [55] reported that as concentration of CNT increases, cetane index increases. Babu et al. [57] also observed that the addition of iron oxide nano particles enhance the calorific value and cetane number of blends.

4. Engine Performance

This section reports the results of various research papers on different nanofluid additives used in diesel engine and its effect on performance characteristics particularly BSFC, BSEC and BTE. Effect of variation of dosing level of nanofluid additives on performance characteristics at full load are shown in Table 1. Most of researchers investigated that BTE was improved and BSFC was lowered with increase in dosing rate of nanofluid additives.

Table 1. Engine performance by adding nano additive in Diesel engine by reseachers.

Fuel	Nano additive	Composition (ppm)	BSFC (kg/kWh)	BTE (%)
D80PSWB20	ZnO	50	0.278	28.8
		100	0.272	29.96
JME2S5W	CNT	25	0.315	27.89
		50	0.308	28.13
		100	0.301	28.45
JME2S15W	Al_2O_3	25	0.33	27.1
		50	0.32	2802
		100	0.31	29.4
Diesel	CeO_2	0	0.280	-
		50	0.260	-
Diesel	CeO_2	0	0.393	25.66
		25	0.3586	23.63

4.1 Brake specific fuel consumption (BSFC)

Brake specific fuel consumption is a measure of utilization of fuel supplied to engine for developing brake power. BSFC is defined as the mass flow rate of fuel per unit brake power developed. Sajith et al. [20] investigated that the addition of cerium oxide reduces BSFC because the presence of cerium oxide oxidizes carbon deposit from engine leading to smooth and efficient operation . Zhang et al. [49] used nanoceria in diesel and obtained reduction in fuel consumption about 12% as nanoceria concentration increases. Basha [21] found that the BSFC was improved for the nanoparticles blended biodiesel emulsion fuels due to the enhance surface area/volume ratio and shorten ignition delay characteristics of nanoparticles, sufficient mass of fuel could have collected in the combustion chamber to obtain a possible catalytic effect in the unit volume of the fuel during the combustion .

Biodiesel emulsion with 100 ppm alumina nanoparticles blended fuels was shown lower BSFC of 0.31 kg/kW h at full load. As calorific value of jatropha biodiesel is lower compared to diesel for the same power output of engine excess amount of fuel consumed during pure biodiesel operation. Hence, brake specific energy consumption (BSEC) was increased. However, the addition of nano Cobalt oxide (Co_3O_4) and Magnalium was shown 2% and 3% reduction in bsec as a result of oxidation reactions in fuel, which improves the combustion rate of fuel at half and full loads respectively [22]. Jelles [29] studied the effect of cerium, iron, and copper base metal additives with and without platinum. The copper additive was resulted in 5% increase in fuel consumption due to delayed combustion caused by the copper additive. Keskin et al. [30] observed maximum reduction in the specific fuel consumption values with 16 µmol/l Mn additives due to the catalyst effect of metallic based additives. The Mn based additive is more effective than Mg based additive. The diesel fuels with metallic based additives were burned well in the cylinders than diesel fuel without metallic-based.

The additives also lead to shorter ignition delay period and slightly greater heat release rates during portions of the expansion stroke which improve power and specific fuel consumption (sfc) values. Keskin et al. [32] dosed Mn and Ni based additives at the rate of 8 µmol/l and 12 µmol/l in the mixtures of 60% tall oil methyl ester and 40% diesel fuel (TE60) to prepare test fuel samples. In comparison with diesel fuel, higher sfc values were measured with biodiesel fuels. This is because of the lower CV of biodiesel fuels result in increase in sfc with biodiesel fuels ranged from 3.22% to 6.00%. Zhu et al. [33] investigated that BSFC decreased with increasing the catalyst dosing ratio under the tested engine conditions. However, the BSFC did not decrease linearly with the catalyst dosing ratio. Test samples were prepared by adding a combustion catalyst by varying volume concentration from 1:20,000 to 1:5000. Ganesh et al. [22] used Magnalium and cobalt oxide nanofluid additives and determine the performance characteristics of Jatropha biodiesel (JBD) in a single cylinder, AC, DI engine.

The lower brake thermal efficiency (BTE) and higher BSFC were obtained due to lower CV of JBD,. However, the addition of Magnalium and cobalt oxide improves BTE significantly as compared to without additives. An improvement in BTE for magnalium additive compare to JBD without additive was about 1%. Mehta et al. [41] prepared stable nanoemulsion adding maximum 0.1% concentration of nano aluminum (n-Al) and nano silicon (n-Si) in water–diesel. Performance test was carried out at a constant speed of 1500 rpm on a single cylinder, 4-stroke, DI diesel engine under varying load condition from 0 to 20 kg. BSFC was reduced by 21% and 37% for nano aluminum (n-Al) and nano silicon (n-Si) blended water–diesel emulsion as compare to diesel. Hydrogen released during the reaction with water emulsified diesel, n-Al and water emulsified diesel, n-Si result in reduction of BSFC. The addition of carbon nanotube in jatropha methyl ester reduces the BSFC at full load. Jatropha methyl ester with 100 ppm concentration of carbon nano tube additive shown lower BSFC of 0.301 kg/kW h as compare to 0.346 kg/kW h of jatropha methyl ester without carbon nano tube [42].

The lower sfc was observed at 100 ppm concentration of each additive which is 0.36 kg/kW h as compare to 0.39 kg/kWh without additives at bmep of 0.44 MPa. Because the cerium oxide provides oxygen for the combustion and carbon nano tube enhanced the reaction rate [40]. The experimental investigation carried out at constant speed of 1500 rpm under varying load condition from 0–100% on single cylinder, four stroke, air cooled diesel engine found that BSFC was decreased as dosing concentration of zinc oxide increased from 50 ppm to 100 ppm [43]. Saraee et al. [48] used silver nano particles of 30–40 nm size concentration ranging from 10–40 ppm in diesel with surfactant of sorbitan monooleate for stability purpose. The test was carried out on six cylinders, DI, Air cooled engine under varying speed. The fuel containing 10 and 20 ppm silver nanoparticles have lowest fuel consumption and about 2% reduction of fuel consumption observed in silver nano particles containing fuel as compared to diesel due to the increase in fuel jet momentum and penetration rate inside the cylinder responsible for uniform distribution of air fuel mixture in the cylinder. The power of engine was also increased up to 20 ppm concentration of silver nano particles and thereafter no significant improvement. Maximum growth obtained is 7–8%.

The maximum increase of brake power was 1.6% at the speed of 1500–3000 rpm for pure biodiesel with 0.1% nano-TiO_2. However, Fangsuwannarak [50] reported that the 0.1% nano-TiO_2 blended fuel has lower brake specific fuel consumption as compared to 0.2% nano-TiO_2. Arockiasamy and Anand [52] reported that the fuel containing 30 ppm cerium oxide and alumina nano particles have about 1.7% higher brake thermal efficiency as compared to neat biodiesel, which is the result of high surface to volume ratio promoting complete combustion . Shaafi and Velraj [53] reported that the BSFC was higher at load below 50% but reduction in bsfc above 75% load was observed. BSFC value for Alumina nano particle containing fuel blend shows about 12% reduction at full load. At 75% and full load, BSEC was reduced due to lower viscosity as compared to 25% load. Santhanamuthu et al. [54] investigated polanga oil–diesel blends with varying composition of polanga oil from 10–30% by weight and iron oxide nanoparticles concentration ranging from 100–300 ppm on single cylinder, 4-s, vertical water cooled DI engine.

They reported that below 60% load, BSEC was maximum up to 26 MJ/kW h, but as load increases above 60%, BSEC reduced to 13.5 MJ/kW h. Singh and Bharj [55] prepared emulsion containing 83% diesel, 15% water and 2% surfactant with dispersion of CNT concentration varying from 50, 100 and 150 ppm. The prepared emulsions were used in single cylinder diesel engine coupled with eddy current dynamometer to obtained performance, emission characteristics. The reduced trend of BSFC was obtained with increasing in concentration of CNT. The minimum BSFC was 0.27 kg/kW h for 150 ppm concentration CNT blended fuel compared to 0.31 kg/kW h for neat diesel due to the water present in fuel rapidly evaporates results in finer spray and also catalytic activity of CNT promotes evaporation rate.

4.2 Brake thermal efficiency (BTE)
Researchers studied the effect of nanofluid additives on brake thermal efficiency (BTE) and reported that nanofluid additives are a promising alternative for improvement in BTE of Diesel engine. Sajith et al. [20] carried out an engine tests with the modified biodiesel at different dosing levels (20–80 ppm) of cerium oxide nanoparticles additive showed an improvement in the BTE of the engine. An improvement of 9%,

4%, and 2% in BTE was observed at higher loads for aluminum, iron and boron nanofuel respectively, as compare to diesel due to enhancement in the calorific values and also promotes complete combustion due to higher evaporation rates, reduced ignition delay, higher flame temperatures and prolonged flame sustenance by Mehta et al. [39, 41].

The CNT added emulsion fuel shown about 2% higher BTE compared to diesel [55]. The carbon nano tube blended jatropha methyl ester emulsion fuel shows improvement in BTE as compare to jatropha methyl ester due to intensive secondary atomization. Jatropha methyl ester with 100 ppm concentration of carbon nano tube additive has shown maximum BTE of 28.13% as compare to 24.8% of jatropha methyl ester at full load [42]. The BTE for cerium oxide and carbon nano tube added diesel– biodiesel–ethanol blend with 100 ppm concentration each was increased by 8.05% [40]. Higher brake thermal efficiency was observed with the addition of zinc nano particles in blends of diesel–pomoplion stearin wax biodiesel as compare to without additives [43]. Banapurmath et al. [51] prepared the fuel samples containing 50 mg graphene, silver and multiwalled carbon nanotubes respectively in one liter Honge oil methyl ester (HOME). Samples was tested on single cylinder, 4stroke DI engine under various load to find engine performance and emission characteristics.

They compared the BTE and found that graphene containing biodiesel have more BTE than MWCNT due to its higher thermal conductivity. The fuel containing nano particles have more BTE than pure Honge oil methyl ester. They reported that the graphene nano additives shows better engine performance and emission characteristics due to its higher thermal conductivity and higher surface area result in improvement in catalytic activity. BTE was increased in alumina nano particle containing fuel blend about 18% as compared to neat diesel at full load condition due to the micro explosion phenomenon of primary droplet in presence of alumina nano particle results in enhance the evaporation rate, responsible for complete release of heat energy leads to increase in BTE [53]. Venkatesan [56] mixed 1 g and 1.5 g nano alumina powder in a one liter of diesel and prepared mixture using sonicator to distribute particles uniformly and reported improvement in BTE up to 6% for 1.5 g alumina concentration. Babu et al. [57] investigated the iron oxide nano particles at 25–50 ppm concentration in diesel on a CRDI engine and observed that presence of iron nano particles improves the combustion efficiency due to more surface area and chemical reactivity, which results in improvement of about 2% BTE in 50 ppm nano iron oxide blended fuel.

5. Exhaust Emission Characteristics

5.1 NOx emission

Reports from researchers on effect of nano additives on NOx are presented in this section. The components of NOx are nitric oxide (NO) and nitrogen dioxide (NO2) which generated during combustion process. Hence, to improve the quality of diesel fuel, various metal additives such as nanometal oxide of manganese oxide (MnO) and copper oxide (CuO) have been selected and doped with diesel for reaching more complete fuel combustion and reducing the amount of exhaust gases [28]. NOx emission was reduced when the platinum/cerium additive used up to 20% [30]. NOx emissions were found at relatively higher with the metallic-based additives probably due to the catalyst effect of metallic additives in the combustion process [30]. NOx emission values are relatively higher with the biodiesel of Mn additives compared to biodiesel with Ni additives. This higher NOx value is probably because of the Mn additives having more catalyst effect on combustion causing increase in the maximum temperature [32]. Mehregan et al. [34] dosed 2.5% Al in decane and ethanol, results in a change in evaporation behavior of the base fluids causing reduction in NOx emission.

Cerium oxide nanoparticles are a thermally stable oxidation catalyst to promote oxidation of hydrocarbon fuel. When using as a fuel additive in CI engine reduces NOx emission [20]. However, rate of NOx emission was increased about 28% for 10 fold nanoceria concentration [49]. NOx emission was increased by 5% and 4% for nano aluminum (n-Al) and nano silicon (n-Si) in water– diesel emulsion respectively due to higher burning temperatures [41]. The CNT blended water emulsion fuel shown significant reduction in NOx emission as a result of water addition and reduced ignition delay [55]. Carbon nano tube added jatropha methyl ester shown lower NOx due to enhance combustion reaction and an improvement in the homogenization of air fuel mixture. Jatropha methyl ester blended with 100 ppm carbon nano tube shown maximum reduction of 372 ppm as compared to jatropha methyl ester at full load [42]. No effect was observed on NOx emission with the addition of zinc oxide in blends of diesel– pomoplion stearin wax biodiesel [43].

The increase in NOx emission was observed for lower concentration on other hand decrease trend was observed for higher concentration [40]. NOx emissions dramatically reduced even at 0.4% concentration of the Fe_3O_4 nanoparticles additives [44]. The NOx emission was reduced by 9% and 7% for alumina and cerium oxide nano particles respectively due to fast evaporation rate. Reduced exhaust gas temperature confirmed the reduction of the NOx emission [52]. Santhanamuthu et al. [54] reported that the presences of iron oxide nano particles reduced the soot oxidation temperature and also take part as a catalyst for reaction of hydroxyl radicals result in reduced amount of NOx emission for blends above 80% load. Babu and Raja [57] used alumina nano particles dosing level varying from 25–75 ppm in diesel. The 2D IC engine model was prepared using ANSA CFD software and tested. The aim of the study was to find the trends of NOx emission using experimental and simulation. They found that variation in results was about 4.5–13.2%. NOx emission effectively reduced up to 38% due to oxygen donating capacity of rhodium oxide [58].

5.2 Hydrocarbon (HC) emission

The literatures on effect of nano particles on HC emission are reviewed and discussed in following section. Hydrocarbon emission is due to incomplete combustion of fuel. Most of researchers reported that hydrocarbon emission was reduced by the addition of nano fuel additives. It was observed that the exhaust gas from engine showed an increase in HC by 4% and 9% with nano aluminum (n-Al) and nano silicon (n -Si) in water–diesel emulsion respectively [41]. The addition of carbon nanotube in jatropha biodiesel result in secondary atomization which reduces the HC emission slightly. Also, carbon nano tube with 100 ppm concentration showed 57 ppm HC emission level as compared to 59 ppm HC emission level without additives [42].

Cobalt oxide and magnalium additive shown a 75% reduction in HC emission at 75% load [22]. Zinc nano particles in blends of diesel–pomoplion stearin wax biodiesel result in the reduction of HC emission as compare to without additives due to improved ignition characteristics [43]. The lowest hydrocarbon emission was observed as 166 ppm for the 50 ppm concentration of cerium oxide and carbon nanotube additive, whereas it was 176 ppm for the diesel–biodiesel–ethanol blends at the bmep of 0.44 MPa [40]. The reduction of hydrocarbon emission up to 33% and 28% was observed for alumina and cerium oxide dosed biodiesel fuel [52].

5.3 Carbon monoxide (CO) emission

The literatures on effect of nano particles on CO emission are reviewed and discussed in following section. The lower value of CO emission was obtained at higher concentration of Mn based additives because the diesel fuels with metallic based additives were burned well in the cylinders than diesel fuel without metallic-based additives [30]. Guru et al. [31] investigated MgO, CuO, MnO2 and CaO additives and observed that the CO was decreased when the Mn additive was dosed to the diesel fuel. It is clearly seen that CO emission concentration of biodiesel fuel decreased with Mn and Ni based additives. When comparing Ni to Mn based additive, the relatively lower CO emission was measured with Mn based additive. It was reported that catalyst effect of these additives improve combustion efficiency [32]. Mehregan et al. [34] numerically investigated that CO emission was reduced by the addition of 2.5% Al in decane and ethanol due to change in evaporation behavior of the base fluids. CO emission was increased due to irregular rise in temperature as well as chamber pressures due to burning of liberated hydrogen [41].

Carbon nano tube blended jatropha biodiesel was shown improvement in combustion due to shortened ignition delay result in the reduction of CO. However, the maximum reduction of CO emission was observed in 100 ppm dosed carbon nano tube jatropha biodiesel fuels [42]. The addition of zinc nano particles in blends of diesel–pomoplion stearin wax biodiesel results in the reduction of CO emission as compare to without additives due to improve ignition characteristics [43]. Zhang et al. [49] observed that the reduction in carbon dioxide emission for 1 and 10 fold concentration of nanoceria is about 6% and 12% respectively. The CO_2 emission shows same trend as that of CO. The combine effect of cerium oxide and carbon nanotube addition in diesel–biodiesel–ethanol blend shows 0.54% CO emission as compared to 0.42% without additives [40]. CO emission was noticeably increased with increasing the dosing level of nanoparticles [44]. The silver nano particle containing fuel reduces the equivalence ratio due to improve atomization and distribution of air–fuel mixture causing reduction in carbon monoxide emission [48]. The maximum reduction of CO emission was found about 29% in 0.1% nano additive added 20% palm biodiesel blend. Also the reduction of CO_2 emission was observed by Fangsuwannarak with adding nano-TiO_2. Because the addition of nano-TiO_2 results in higher oxidation of carbon promoting complete combustion [50].

6. Conclusion

According to analysis of research papers, it can be concluded that range of nano fluid additives can be used as additives in diesel and biodiesel due to increased surface area to volume ratio, increased in catalytic activity in nano size metal oxides and metals. Nano fluid increases better combustion due micro explosion phenomenon. The results of study may be summarized as follows:

- It can be concluded that addition of nano particles improves the calorific value and cetane number of diesel and biodiesel fuel. However viscosity, flash point and density of fuel are slightly increased.
- It is evident from literatures that nano fluid enhances combustion of fuel due to improvement in heat transfer, catalytic activity, air fuel mixing rate.
- The results showed that brake specific consumption decreases with dosing of nano particles additive due to enhanced calorific value, catalytic oxidation and complete combustion of fuel.
- It is evident from the literatures that the higher brake thermal efficiency was obtained using nano fluid additives by promoting complete combustion. The results showed that increasing dosing level of nano fluid additives increases the brake thermal efficiency.
- Most of the additives showed reduction in NOx due to higher cetane number and reduction in HC due to higher evaporation rate and catalytic oxidation.
- Lower smoke emission was observed by most of the authors due to higher evaporation rate, reduced ignition delay.
- Some authors observed increase in CO emission and some authors observed decrease in CO emission due to improved ignition characteristics with nano fluid additives. At higher concentration of nano fluid additives, the higher CO emission was observed.
- It can be concluded from few studies that increase in cylinder pressure and heat release rate using nano particles was obtained. Also, higher evaporation rate was obtained in researches.

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References

[1] Murugesan A, Umarani C, Subramanian R, Nedunchezhian N. Bio-diesel as an alternative fuel for diesel engines—A review. Renew Sustain Energy Rev 2009;13:653–62.
[2] Mohd Noor C, Noor MM, & Mamat R,.Biodiesel as alternative fuel for marine diesel engine applications: A review. Renew Sustain Energy Rev 2018;94, 127-142.
[3] Najafi G, Ghobadian B, Yusaf T, Ardebili SMS, Mamat R. Optimization of performance and exhaust emission parameters of a SI (spark ignition) engine with gasoline eethanol blended fuels using response surface methodology. Energy 2015;90, 1815-1829.
[4] Murat K, Gokhan E, Murat H. Effects of the blends containing low ratios of alternative fuels on the performance and emission characteristics of a diesel engine. Fuel 2013;112:537–41.

[5] Dhar A, Kevin R, Agarwal AK. Production of biodiesel from high-FFA neem oil and its performance, emission and combustion characterization in a single cylinder DICI engine. Fuel Proces Technol 2012;97:118–29.
[6] Sharma YC, Singh B. Development of biodiesel from karanja, a tree found in rural India. Fuel 2008;87:1740–2.
[7] Chen KS, Lin YC, Hsieh LT, Lin LF, Wu CC. Saving energy and reducing pollution by use of emulsified palm-biodiesel blends with bio-solution additive. Energy 2010;35:2043–8.
[8] Dantas Neto AA, Fernandes MR, Barros Neto EL, Castro Dantas TN. and Moura MCPA.Alternative fuels composed by blends of nonionic surfactant with diesel and water: engine performance and emissions. Braz J Chem Eng 2011;28 (03):521–31.
[9] FuWB, Hou LY, Wang LP, Ma FH. A study on ignition characteristics of emulsified oil containing flammable fuel. Fuel Proces Technol 2003;80:9–21.
[10] Alahmer A, Yamin J, Sakhrieh A, Hamdan MA. Engine performance using emulsified diesel fuel. Energy Convers Manag 2010;51:1708–13.
[11] Bulent Koc A, Abdullah M. Performance and NOx emissions of a diesel engine fueled with biodiesel-diesel-water nano emulsions. Fuel Proces Technol 2013;109:70–7.
[12] Nadeem M, Rangkuti C, Anuar K, Haq MRU, Tan IB, Shah SS. Diesel engine performance and emission evaluation using emulsified fuels stabilized by conventional and gemini surfactants. Fuel 2006;85:2111–9.
[13] Selim MYE, Elfeky SMS. Effect of diesel/water emulsion on heat flow and thermal loading in a precombustion chamber diesel engine. Appl Thermal Energy 2001;21:1565–85.
[14] Yang WM, An H, Chou SK, Vedharaji S, Vallinagam R, Balaji. Emulsion fuel with novel nano-organic additives for diesel engine application. Fuel 2013;104:726–31.
[15] Sadhik Basha J, Anand RB. An experimental study in a CI engine using nanoadditives blended water–diesel emulsion fuel. International journal of green energy, vol. 8 (3); p. 332–48.
[16] Dreizin EL. Metal-based reactive nanomaterials. Prog Energy Combust Sci 2009;35:141–67.
[17] Fangsuwannarak K, Triratanasirichai K. Effect of metalloid compound and bio solution additives on biodiesel engine performance and exhaust emissions. Am J Appl Sci 2013;10(10):1201–13.
[18] Tock Richard W, Hernandez Arlene, Sanders Kenneth J, et al. Nano-sized zinc oxide particles for fuel. US Patent Application 20120204480; 2012.
[19] Sajeevan AC, Sajith V. Diesel engine emission reduction using catalytic nanoparticles: an experimental investigation. Adv Mech Eng 2013:1–9.
[20] Sajith V, Sobhan CB, Peterson GP. Experimental investigations on the effects of cerium oxide nanoparticles fuel additives on biodiesel. Adv Mech Eng 2010:1–6.
[21] Basha JS, Anand RB. Role of nanoadditive blended biodiesel emulsion fuel on the working characteristics of a diesel engine. J Renew Sustain Energy 2011;3 (023106):1–17.
[22] Ganesh D, Gowrishankar G. Effect of nano-fuel additive on emission reduction in a biodiesel fuelled CI engine 978-1-4244-8165-1/11; 2011. p. 3453–59.
[23] Kannan GR, Karvembu R, Anand R. Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel. Appl Energy 2011;88:3694–703.
[24] Shafil MB, Daneshvar F, Jahani N, Mobini K. Effect of ferrofluid on the performance and emission patterns of a four stroke diesel engine. Adv Mech Eng 2011;2011:529049.
[25] Basha JS, Anand RB. The influence of nano additive blended biodiesel fuel on the working characteristics of a diesel engine. J Braz Soc Mech Sci Eng 2013.
[26] Kao MJ, Ting CC, Lin BF, Tsung TT. Aqueous aluminum nanofluid combustion in diesel fuel. J Test Eval 2008;36(2):1–5.
[27] Selvan VAM, Anand RB, Udaykumar M. Effect of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ehanol blends on the performance and emission characteristics of a CI engine. ARPN J Eng Appl Sci 2009;4(7):1–6.
[28] Lenin MA, Swaminathan MR, Kumaresan G. Performance and emission characteristics of a DI diesel engine with a nanofuel additive. Fuel 2013;109:362–5.

[29] Jelles J, Makkee M, Moulijn JA. Ultra low dosage of platinum and cerium fuel additives in diesel particulate control. Top Catal 2001;16/17(1–4):269–73.
[30] Keskin A, Guru M, Altiparmak D. Influence of metallic based fuel additives on performance and exhaust emissions of diesel engine. Energy Convers Manag 2011;52:60–5.
[31] Guru M, Karakaya U, Altiparmak D, Alicilar A. Improvement of diesel fuel properties by using additives. Energy Convers Manag 2002;43:1021–5.
[32] Keskin A, Guru M, Altiparmak D. Biodiesel production from tall oil with synthesized Mn and Ni based additives: effects of the additives on fuel consumption and emissions. Fuel 2007;86:1139–43.
[33] Zhu M, Ma Y, Zhang D. Effect of a homogeneous combustion catalyst on the combustion characteristics and fuel efficiency in a diesel engine. Appl Energy 2012;91:166–72.
[34] Mehregan M, Moghiman M. Numerical investigation of effect of nanoaluminum addition on NOx and CO pollutants emission in liquid fuels combustion. Int J Mater Mech Manuf 2014;2(1):60–3.
[35] Balamurugan K, Tamilvanan A, Anbarasu M, Akil MS, Srihari S. Nano-copper additive for reducing NOx emission in soya bean biodiesel-fuelled CI engine. J Biofuels Year 2013;4(1):1–8.
[36] Senthilraja S, Karthikeyan M, Gangadevi R. Nanofluid applications in future automobiles: comprehensive review of existing data. Nano-Micro Lett 2010;2 (4):306–10.
[37] Luman JR, Wehrman B, Kuo KK, Yetter RA, Masoud NM, Manning TG, et al. Development and characterization of high performance solid propellants containing nano-sized energetic ingredients. Proc Combust Inst 2007;31:2089–96.
[38] Sonawane S, Patankar K, Fogla A, Puranik B, Bhandarkar U, Kumar SS. An experimental investigation of thermo-physical properties and heat transfer performance of Al2O3-Aviation turbine fuel nanofluids. Applied Thermal Engineering, vol. 31, 201. p. 2841–849.
[39] Mehta RN, Chakraborty M, Parikh PA. Nanofuels: combustion, engine performance and emissions. Fuel 2014;120:91–7.
[40] Selvan VAM, Anand RB, Udayakumar M. 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 2014;130:160–7.
[41] Mehta RN, Chakraborty M, Parikh PA. Impact of hydrogen generated by splitting water with nano-silicon and nano-aluminum on diesel engine performance. Int J Hydrogen Energy 2014;39:8098–105.
[42] Basha JS, Anand RB. Performance, emission and combustion characteristics of a diesel engine using carbon nanotubes blended jatropha methyl ester emulsions. Alex Eng J 2014;53:259–73.
[43] Karthikeyan S, Elango A, Prathima A. Performance and emission study on zinc oxide nano particles addition with pomoplion stearin wax biodiesel of CI engine. J Sci Ind Res 2014;73:187–90.
[44] Sarvestany Farzad A, Bajestan EE, Mir M. Effects of magnetic nanofluid fuel combustion on the performance and emission characteristics. J Dispers Sci Technol 2013 10.1080/01932691.2013.874296.
[45] Venkatesan SP, Kadiresh PN, Kumar KS. Experimental investigation of aqueous cerium oxide nanofluid blend in diesel engine. Adv Mater Res 2014;938:286–91.
[46] Imdadul HK, Masjuki HH, Kalam MA, Zulkifli NWM, Rashed MM, Rashedul HK, Monirul IM, Mosarof MHA. comprehensive review on the assessment of fuel additive effects on combustion behavior in CI engine fuelled with diesel biodiesel blends. RSC Adv 2015;5:67541–67. http://dx.doi.org/10.1039/c5ra09563h.
[47] Shaafi T, Sairam K, Gopinath A, Kumaresan G, Velraj V. Effect of dispersion of various nanoadditives on the performance and emission characteristics of a CI engine fuelled with diesel, biodiesel and blends—a review. Renew Sustain Energy Rev 2015;49:563–73.
[48] Saraee HS, Jafarmadar S, Taghavifar H, Ashrafi SJ. Reduction of emissions and fuel consumption in a compression ignition engine using nanoparticles. Int J Environ Sci Technol 2015;12:2245–52. http://dx.doi.org/10.1007/s13762-015-0759-4.
[49] Zhang J, Nazarenko Y, ZhangL, Calderon L, Lee K, Garfunkel E, Schwander S, Tetley TD, Chung KF, Porter AE, Ryan M, Kipen H, Lioy PJ, Mainelis G. Impacts of a nanosized ceria additive on diesel

engine emissions of particulate and gaseous pollutants. Environ Sci Technol 2013. http://dx.doi.org/10.1021/ es402140u American Chemical Society.
[50] Fangsuwannarak K, Triratanasirichai K. Improvements of palm biodiesel properties by using nano-TiO_2 additive, exhaust emission and engine performance. Roman Rev Precis Mech Opt Mechatron 2013;43:111–8.
[51] Banapurmath NR, Sankaran R, Tumbal AV, Narasimhalu TN, Hunashyal AM, Ayachit NH. Experimental investigation on direct injection diesel engine fuelled with graphene, silver and multiwalled carbon nanotubes-biodiesel blended fuels. Int J of Automot Eng Tech 2014;3(4):129–38.
[52] Arockiasamy P, Anand RB. Performance, combustion and emission characteristics of a DI diesel engine fuelled with nanoparticle blended jatropha biodiesel. Period Polytech Mech Eng 2015;59(2):88–93. http://dx.doi.org/10.3311/ PPme.7766.
[53] Shaafi T, Velraj R. Influence of alumina nanoparticles, ethanol and isopropanol blend as additive with diesel soybean biodiesel blend fuel: combustion, engine performance and emissions. Renew Energy 2015;80:655–63. http://dx. doi.org/10.1016/j.renene.2015.02.042.
[54] Santhanamuthu M, Chittibabu S, Tamizharasan T, Mani TP. Evaluation of CI engine performance fuelled by diesel-polanga oil blends doped with iron oxide nanoparticles. Int J Chem Tech Res 2014;6(2):1299–308.
[55] Singh N, Bharj RS. Effect of CNT-emulsified fuel on performance, emission and combustion characteristics of four stroke diesel engine. Int J Current Eng Tech 2015;5(1):477–85.
[56] Venkatesan SP. Influence of aluminum oxide nanoparticle additive on performance and exhaust emissions of diesel engine. American-Eur J Sci Res 2015;10(2):88–92. http://dx.doi.org/10.5829/idosi.aejsr.2015.10.2.22011.
[57] Babu KR, Raja RB. Theoretical and experimental validation of performance and emission characteristics of nanoadditive blended diesel engine. Int J Res Aer Mech Eng 2015;3(5):18–31.