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Mini Review

Effect of various nanoadditives on the performance and emission characteristics of a diesel engine fuelled with jojoba biodiesel – diesel blends: A review

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Abstract

The review reports the results of various researches work on the engine performance and emission characteristics of diesel engine using different nanoadditives in jojoba biodiesel - diesel blends. Blending of diesel with biodiesel in a diesel engine has gained importance, due to its economical and environmental benefits. Jojoba biodiesel gained an importance as an alternative fuel over conventional diesel fuel even with their unfavorable effects of power reduction. The wide spread usage of nanoadditives to improve the combustion quality may be a good solution of this problem. Blending of nanoparticles as an additives in biodiesel – diesel blends improves the thermophysical properties, such as thermal conductivity, mass diffusivity and high surface area-to-volume ratio. Based on the results available in the literature, it has been found that nanoadditives with jojoba biodiesel - diesel blends improve the performance of diesel engine and reduced the emission of toxic gases depending upon the dosage of the nanoadditives.

Keywords: Nanoadditives; Jojoba biodiesel; Thermophysical; Combustion quality

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Introduction

Nowadays, concerns have been raised about the limited resources of fuel oil and the environmental issues which directly linked to the combustion of these fuels (1). The above-mentioned issues motivated the researchers to find out some new alternative and renewable sources of energy, which are more environmental friendly. Diesel engine plays an important role in industrial sectors due to their easy, high reliability, durability and good exhaust emission behavior. Diesel engines can use variety of fuels such as diesels, fuel oil, biodiesel, etc (2).

Biodiesel is considered as a renewable, clean burning diesel and a better replacement of available conventional petroleum based fuels. The edible (sunflower, soybean, rapeseed etc.) and non-edible vegetable oils (palm, jatropha, jojoba etc.)

were served as potential feedstock to produce biodiesel (3). Non-edible oils as feedstock for biodiesel preparation gained much more attention due to their lower demand in comparison with food crops (4). Jojoba, *Simmondsia chinensis* (Link) Schneider, belongs to family Simmondsiaceae, is a known non edible oilseed crop. Jojoba is a native shrub of Northern Mexico, USA and Baja California (5). Raw oils can be converted into their methyl esters (biodiesel) using different methods, out of them transesterification method is commonly used because it is simple, cost effective and produce good quality biodiesel (6).

Biodiesel can be directly used in diesel engines but it's better to improve its quality by some modification. The fuel modification can be achieved by several methods such as blending of solvents, market diesel, raw plant oil, nanoparticles etc. (7). These modifications can help the researchers to achieve the specific fuel properties and to improve the engine performance. With the help of nanotechnology nano-scale energetic materials are produced which are much more advantageous as are nano-sized materials (8). Most of the researchers conducted their experiments with metal nanoadditives (9), metal oxide nanoadditives (10), magnetic nano fluid additives (11)and water diesel nanoparticle, emulsion (12), water diesel carbon nano tube emulsion (13), and nano organic additives (14) to the diesel fuel. There are only a group of researchers were found in previous literature who worked on jojoba biodiesel – diesel blends with nanoparticle addition (15-20).

In 2014, Attia and his coworkers carried out an experiment to study the effect of Al_2O_3 nanoparticles as nanoadditives in jojoba biodiesel - diesel blends on single cylinder diesel engine and they found a slight improvement in engine performance and lower CO and HC emission in comparison to blend without Al_2O_3 nanoadditive (15). Later the same group of researchers continues their work by using different nanoadditives (Al_2O_3, MWCNTs) with jojoba biodiesel – diesel blends (16-19). However, in 2018 they again conducted their experiment using different nanoadditive made of titanium oxide (TiO_2) mixed with jojoba biodiesel – diesel – n-hexane blend (J30D5H) and study their effect on diesel engine performance and exhaust gas emission (20).

Effects of various jojoba biodiesel blend + nanoadditives on engine performance

1. Brake thermal efficiency

Brake thermal efficiency is defined as the relationship between engines generated break power and transferred energy to engine. The performance of engine using fuel blends can be estimated by brake thermal efficiency. Nanoparticles addition to fuel blends improve the combustion efficiency by improving the heat mass transport properties (21).

There are investigations on the variation in brake thermal efficiency using jojoba biodiesel blends with Al_2O_3 NPs at dosage levels of 10 and 50 mg and diesel (15). The value of brake thermal efficiency is increased in comparison with pure diesel. This may be due to the effect of nanoparticle on biodiesel blend, which improve its surface-area-to-volume ratio leads to react more amount of fuel with air.

Another study reported the blending of n-hexane with jojoba biodiesel blends with TiO_2 nanoadditives improved the spray characteristics by decreasing the viscosity of the blended fuels. Low viscosity helps in increasing the fuel combustion and thus the brake thermal efficiency gets increased. The addition of TiO_2 nanoparticles increased the brake thermal efficiency by 15% and boosts the performance of engine consequently (20).

2. Brake specific fuel consumption

Brake specific fuel consumption is defined as the ratio of the fuel used by engine to the power generated by engine with respect to the time (22). Engine load is an important parameter because as we increase the load of the engine, the value of brake specific fuel consumption gets reduced (23). Other than engine load some more parameters (calorific value, density, volumetric fuel injection and viscosity) also affects the value of brake specific fuel consumption (24).

Attia and his co-workers investigated the effect of Al_2O_3 NPs on jojoba biodiesel-diesel blends. The result showed that there was a considerable change in fuel properties. The authors reported that the fuel sample JB20DA produced the maximum amount of BSFC (~760 g/kW-h) at 50 mg Al_2O_3 additive concentration in comparison to the other blends (15).

One of the recent studies conducted in 2018, showed the reduction in brake specific fuel consumption about 12% with the addition of Al_2O_3 nanoparticles (19). The minimum brake specific fuel consumption is achieved, which was slightly lower than diesel fuel at the dose levels of 30-40 mg/l. Further addition of Al_2O_3 nanoparticles beyond these levels; increase the brake specific fuel consumption value. Another study conducted by same group of researchers found the same results with TiO_2 NPs (19).

Effects of various jojoba biodiesel blend + nanoadditives on engine combustion characteristics

1. Ignition delay

The ignition delay period in the diesel engine has a significant influence on engine design and performance. The ignition delay can be divided into two parts, physical delay and chemical

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delay. It depends mainly on fuel properties and engine operating conditions in conjunction with fuel injection system features. The addition of nanoadditives leads to a decrease the ignition delay (25). The reason is attributed to the higher surface area to volume ratio and higher thermal conductivity of nanoadditives which enhance the evaporation rate resulting in a reduction in physical delay (26).

In an experimental study conducted by El-Seesy et al. with multi well carbon nanotubes (MWCNTs) mixed in a jojoba biodiesel-diesel blend in order to investigate the combustion characteristics of diesel engine, revealed that the effect of MWCNTs shortens the ignition delay as a result in higher gross heat release rate and advancement of the peak gross heat release rate (18). It finally resulted in better atomization of fuel and proper air fuel mixing.

El-Seesy et al. again conducted an experiment on alumina nanoparticles with diesel jojoba biodiesel fuel in a diesel engine revealed decrease ignition delay. The ignition delay for JB20D mixture fuel is slightly higher by about 0.5 CA as compared to diesel fuel. This is attributed to the higher viscosity and molecular weight of JB20D, which lead to an increase of fuel droplet size and vaporization time (19). The reason is attributed to the higher surface area to volume ratio and higher thermal conductivity of the Al_2O_3 nanoparticles which enhanced the evaporation rate, resulting in a reduction in physical delay. These results were confirmed with others cited in the literature (21).

2. Cylinder Pressure

The cylinder gas pressure of diesel, diesel biodiesel fuel and nanoparticle blended diesel biodiesel fuel have shown near similar trends of variation with crank angle. The change of cylinder pressure as a function of the crank angle during the end of the compression stroke and throughout the initial part of the expansion stroke was recorded for the test fuels. With the advancement in fuel injection timing, along with high injection pressure of biodiesel fuels, the combustion process starts earlier which provides shorter ignition delay might be the possible reason for high cylinder pressure (27).

The addition of MWCNTs to JB20D mixture led to accelerating combustion process. The MWCNTs has a higher thermal conductivity which is about 2000 times greater than that of JB20D blends. Therefore, the evaporation rate of fuel droplet is increased, which resulted in a shortened ignition delay. Another factor is the higher surface area to volume ratio of Multi-walled carbon nanotubes, which enhanced the heat transfer between the particles and the fuel droplets resulted in increased peak pressures (18). Few other studies also obtained similar results when using MWCNTs additives to diesel-biodiesel blended fuel (28-30).

Effects of various jojoba biodiesel blend + nanoadditives on engine emission performance

Basically engine emissions are divided into two different categories, the first one is produced due to the results of high temperature of combustion chamber like NOx and second one is produced resulting from incomplete combustion of fuel and lower combustion temperature like HC and CO_2 (29). CO is produced as a result of incomplete combustion or low combustion time in the engine or lower temperature of the combustion chamber (31). On the other hand, incomplete combustion of diesel or fuel would lead to the production of the HC. Soot is produced by incomplete combustion of the hydrocarbon fuel and is observed in the dark exhaust effluents. In comparison with petrol based engines, diesel engine emits very low concentration of hydrocarbons (HC), Nitrogen oxides (NOx) and carbon oxides (CO, Cox). But with the help of fuel modifications (nanoadditives) these emissions will further be decreased. In the following section, we summaries the effect of different nanoadditives with different jojoba biodiesel blends on the engine emission performance.

1. Carbon monoxide emission

Many authors concluded that as they increase the proportion of jojoba biodiesel and nanoadditives in blends, the carbon monoxide emission gets decreased (Table 1). Addition of nanoadditives to blends increase the amount of oxygen will result in comprehensive fuel combustion (32).

The aluminium oxide (Al_2O_3) nanoparticles were added to jojoba biodiesel blends in fractions of 10 and 50 mg, the result suggested that there were considerable reduction in CO emission (16, 19). Lower CO emission probably due to the increase in surface-to-volume ratio, leads to the great mixing of air to fuel resulting in higher catalytic activity (33). It was found that the CO emissions were lower in compare to either diesel fuel or JB20D fuel blend, irrespective of the nanoadditive concentration. The maximum reduction in CO emissions was found at the dose of 20–30 mg/l. These results were supported by the previous findings (34-36).

The multi well carbon nanotubes (MWCNTs) as additive were also used by the same group of researchers (16-18). They found the reduced emission of CO at 20-40 mg MWCNTs. One of the other studies showed the effect of titanium oxide (TiO_2) nanoparticle with jojoba biodiesel + n-hexane + diesel blends (J30D5H). They concluded that at the

Table 1. Comparison of emission parameters with various jojoba biodiesel blends and nanoadditives

Engine Specification	Biodiesel blends	NPs Type and Dosage	Lowest Emission			Reference
			CO	NOx	HC	
Single cylinder, direct injection diesel engine	Jojoba biodiesel + diesel blend JB20D	Al_2O_3 Nps, 10 - 50 mg	20 – 30 mg	20 – 30 mg	20 – 30 mg	(19)
Single cylinder, direct injection diesel engine	Jojoba biodiesel + n-hexane + diesel blend J30D5H	TiO_2 NPs, 25 mg and 50 mg	50 mg	0 mg	25 mg, 50 mg	(20)
Single cylinder, direct injection diesel engine	Jojoba biodiesel + diesel blend JB20D	Carbon nanotubes 10 - 50 mg	20 – 40 mg	20 mg	20 – 40 mg	(16-18)
Single cylinder, direct injection diesel engine	Jojoba biodiesel + diesel blend JB20D	Al_2O_3 Nps, 10 - 50 mg	30 mg	20 mg	30 mg	(15)

concentration of 50 mg (TiO_2) to jojoba biodiesel blend reduced CO emission by 20% (18).

2. Nitrogen oxide emissions

Nitrogen oxides (NOx) in the exhaust emission consist of nitric oxide (NO) and nitrogen dioxide (NO_2) (37). Many researchers blended different additives (metal-based, oxygenated, cetane improver etc) with biodiesel to decrease the emission of NOx (38). But the investigations revealed that the emission of NOx gets increased with the increase in concentration of blended nanoparticles (29) The increase in NOx emission may be due to the increase in cylinder temperature and thus the existence of a greater chance for thermal NOx formation (39).

An earlier study used Al_2O_3 NPs in jojoba biodiesel blends to improve the engine emission performance and they found the 20 mg concentration of Al_2O_3 NPs reduced the NOx emission (15). Same results were obtained by using Multi walled carbon nanotubes (MWCNT) 20 mg (16, 17) with jojoba biodiesel blends. The above studies showed the reduction of NOx emission at 20 mg among different concentration of NPs, but showed higher emission in comparison with jojoba biodiesel – diesel blend without NPs. In contrast, lower emission of NOx with NPs was observed in comparison to that of without NPs addition (18).

3. Unburned hydrocarbons (UHC) emissions

Incomplete combustion of diesel or fuel leads to the emission of unburned hydrocarbons (UHC). The incomplete combustion due to incomplete/ distorted flame propagation, because of either too rich or too lean mixture, low charge temperature and less injection pressure inside the cylinder are found to be liable for higher level of hydrocarbon emissions (40). Experimental studies on nanoparticle added diesel, biodiesel fuels in a CI engine showed that nanoparticle inclusion with fuel acts as oxidizing catalyst accelerates the flame propagation inside the cylinder, which lowers the carbon activation temperature and promotes more complete combustion. All these factors mainly inhibit the hydrocarbon emissions from nanoparticle mixed diesel, biodiesel fuel blends (41).

The MWCNTs additives had a remarkably positive effect on UHC emissions (18). Using JB20D led to a considerable increase in UHC emissions compared to pure diesel fuel. The reason for this influence may be due to the prolonged delay period and higher values of viscosity of JB20D that disturb the fuel atomization and vaporization and thus, a longer time was required to attain complete combustion. Another reason may be due to the incorrect combustion of layers approaching the cylinder wall. These layers would carry a great fraction of hydrocarbons which escape from the denser and longer penetrated fuel spray in case of JB20D, and hence more UHC was emitted in the exhaust gases. Similar trends of results were also quoted by various researchers when experimenting with different blends of nanoparticle diesel, biodiesel fuels in a CI engine (35, 42).

Conclusion

Based on the above review, it is understood that nanoadditives plays an important role in improving the fuel combustion, enhancing the engine and reduced the exhaust emissions. These engine properties depends upon the type of base fuel used, nanoadditive concentration, blending technique and the operation condition of the diesel engine. Nanoadditives like Al_2O_3, MWCNTs and TiO_2 shows good results as additives with jojoba biodiesel - diesel blends in all aspects. Therefore, blending the optimal range of nanoadditive is the key to get enhanced performance and reduced emission in a diesel engine.

Competing interest

The authors declare that they have no competing interests.

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Author's contribution

SA design and writes the manuscript. SK coordinates and corrects the manuscript. Both the authors read and approved the final manuscript.

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