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Impact of Alumina Nanoadditives on Operation and Emission Attributes of Diesel Engine

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This paper collectively report work of many researchers on engine operation and emissions of diesel engine with alumina nanoadditive in diesel blends. Fuel blending is a very common and popular practice as compared to making changes in engine design or treating the exhaust gases for hazardous emissions. Alumina nanoadditive related findings are encapsulated here to review the pros and cons of various alternative fuels for better performance and reduced harmful emissions. Many recent researches are now focussed on nanoadditive over microadditives for their high specific surface area, much better combustion characteristics than micron sized additives and shorter ignition delays. Easy dispersion and suspension in liquid fuels can be obtained by Nanoparticles. This review focus on the effect of alumina nanoadditives on the fuel efficiency, brake thermal efficiency, emissions and a summary of the observation from literature is presented here.

Keywords: Biodiesel, BSFC, BTE, Nanoadditives, NO_x emissions

Introduction

Diesel engines have been consistently effective in the field of transportation, agronomics and commercial sectors because of reliable standards and being highly efficient. Diesel engines are able to operate at lean air-fuel mixture and work at higher compression ratios in contrast to petrol engines. On the other hand diesel engines result in major environmental problems. Gases exhausted from diesel engines cause unnatural climatic changes, global warming and greenhouse effects.

In the present era where we have increased number of automobiles on the road and with the government imposing firm rules have impacted consumers and engine manufacturers to heed emission standards. Researchers focus on substitute fuels for diesel engine to upgrade operation criteria and control pollution. Due to swift exhaustion of fossil fuel resources and the energy crises, we require alternative options to serve the increasing worldwide population for renewable and eco-friendly resources. High consumption of energy is adversely affecting our environment which can be controlled by resources that can fulfill high energy demand without affecting the environment. Fossil fuel depletion in the immediate years leading to inflation in fuel prices has drawn attention towards economic and environment friendly fuel alternatives.[1]

A lot of research work has been reported where biodiesel seem to be a promising alternative fuel which can be composed from edible, non edible plants, animal fats and waste cooking oils.[2] Biodiesel are biodegradable, environment friendly, sulfur free, non toxic and have high oxygen content. Biodiesels can be used in engine without any design modification. The performance of biodiesel is limited due to the dominating nitrogen oxides (NO_x) emissions during combustion in both biodiesel and biodiesel blends.[3] Vegetable oils are emerging as a best option as alternative fuel but requires modification at the same time.[4] Biodiesels are procured from diverse root of vegetable oils such as *Pongamia pinnata*, peanut, canola oil and are contemplated as a prospective source of substitute fuel for diesel engine. Vegetable oils are attained from numerous oil seed crop sources and are environment friendly. They can be used alone or can be blended with diesel.

On the contrary, vegetable oils pose numerous problems in terms of low volatility and high viscosity as compared to diesel and lead to choking of injector and engine deposits. Any feedstock can be modified to produce biodiesel fuel to improve the properties

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and to persuade safe utility of vegetable oil in diesel engine. Many metal based additives are also announced and claim to reduce emissions from diesel engine. Metal based additives are second hand to catalyst in the fuel to assist combustion. Nanoparticles are also added as a catalyst to improve specific properties of fuel.[5] Many researchers have reported improvement in cetane number and calorific value on addition of nanoadditive. Nanoparticles are effective as fuel additives to improve the combustion quality, reduced ignition delay, reduced heat release rate, and increased overall efficiency. Researchers are constantly looking for promising nanoadditives to enhance performance of diesel and its blends and to reduce emissions coming from them. This review is focussed on alumina nanoadditives in diesel and biodiesel blends because of its superior properties as presented in the previous studies that have considerable impact on engine operation and emissions.

Most of the contributions by researchers are to reduce emission level of pollutants in diesel engines by somehow looking for moderation in these three categories:

1) Design of engine
2) Fuel blending
3) Treatment of exhaust gas

A major category research in this field is focused on fuel adulteration so as to attain specific fuel properties and thereafter improving engine operation while scaling down emissions without redesigning engine.

Assessment of Alumina Nanoparticles as Additive in Diesel and Blends

With growth of population and increase in energy consumption, our dependence on continuous striving design, development and improvement of high energy efficient diesel engines with emissions at low levels escalated. In this consideration, various approaches have been exercised to enhance better and efficient engine performance in terms of fuel reformation, engine design amendment, and handling of exhaust gas. Grounds for fuel reformation support improvement in combustion for acquiring low fuel squandering and emission control. Curtailment in hazardous emissions can be achieved without any amendment in engine design with use of biodiesel and its blends provided increased consumption of fuel and decline in brake thermal efficiency (BTE). Over the last few years application of nanoparticles as fuel additive and catalyst is highly surfacing due to its large surface area for a given volume and oxidizing capacity when diffused in any base fuel.[6] Improved ignition temperature and shortening in ignition lag is imparted by nano-additives being base fuel additive and improved surface to volume ratio inevitably increase the dispersal of the fuel and oxidizer. It is established from previous literature assessment that nanoparticles when blended with diesel-biodiesel blends enhances fuel properties and stimulate thorough combustion which improves engine operation as well as minimize engine emissions.

Analysis of previous researches and studies manifest their concentration on adding vegetable oil, bio diesel and cooking oil being fit for use in diesel engines.[7] While alcoholic additives being potentially explored in many engines and are in a rudimentary stage with potential for development to implement as an additive in most of fossil fuels. Current research focuses on adding metal oxides as additives to enhance the engine operation. MWCNT additive blend with diesel and biodiesel noticeably reduce the brake specific fuel consumption (BSFC), NOx emissions with enhanced Power and Torque.[8] Better emission and reduction in smoke was noted when blended with CNT additives, alumina nanoadditives and their combinations.

Numerous studies regarding nanodiesel are issued mostly amid past ten years. Oxygenated and metallic base compounds function as combustion stimulus for hydrocarbon fuels. On that account, nanodiesels hold a future to boost the combustion efficiency and to minimize the air pollutants.[9] Current proceedings in nanoadditives and nano fuels facilitate manufacturing of nano-sized particles even under 100 nm.[10] The nanodiesel fuels together with alumina nanoparticles have advantages over micron sized particles (Fig. 1); because of unlikeness of congestion in filter and fuel injector.[11] The stability of nanoparticles in base fluid is an important subject of concern for scientists and researchers.[12]

Adding alumina nanoparticle to diesel-biodiesel blends changes their physiochemical property which in succession alters the engine performance, combustion characteristics and effect emission also. The changes are attributed to various grounds such as change in viscosity, change in calorific value, oxygen content of fuel, catalytic combustion and much more. The significance of adding alumina nanoadditive in diesel-biodiesel blends on engine operation and emission attributes have been discussed.

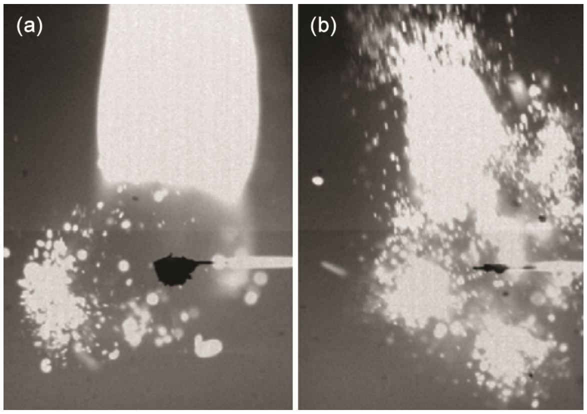

Fig. 1 — Microexplosion behavior for droplets (a) Alumina nanoparticle (b) Alumina micron sized particle

Engine operation parameters

Brake Specific Fuel Consumption

Brake specific fuel consumption differs with change in load or brake mean effective pressure. Large surface area to volume ratio encourages ignition with increasing evaporation rates. An increase in dosing level of nanoparticles, ignition delay is reduced which reduces fuel consumption of nanoparticle blended diesel and biodiesel blends as compared to neat diesel.[13] But in some cases despite adding the nanoparticles to diesel and its blends, it is seen that the BSFC is increased which is stated to be attributed to increase in viscousness at some dosing levels.

Brake Thermal Efficiency

Previous literature account the enhancement of thermal efficiency with an increase in load as it boosts the temperature and promotes combustion thereby increasing the thermal efficiency.[14] Alumina nanoparticle dosing in diesel and its blends behave as catalyst in combustion process, increasing the oxygen content and calorific value of fuel.[15] It is reported to have shorter ignition delay with increased heat transfer rates. Alumina nanoparticle-diesel and its blends have been observed with enhanced brake thermal efficiencies in contrast to neat diesel.[16] However in some cases on increasing the nanoparticle dosage on or above 50 ppm, thermal efficiency decreases as compared to thermal efficiency at low dosage levels which is claimed to be attributed to increased fuel consumption because of higher viscosity due to increased dosing level. However BTE of alumina nanoparticle blended diesel is always higher than neat diesel.

Emission Characteristics

Nitrogen Oxide Emissions

Emissions of NO_x increases with load as temperature increases with enhancement in load and NO_x formation occur at high temperatures. Emissions of NO_x decrease with an increase in blending of alumina nanoparticle in neat diesel as reported in the literature as alumina nanoparticle reduce the ignition delay period.[17] Biodiesel-diesel blends with alumina nanoparticle tend to have higher NO_x emissions in contrast to neat diesel because of formation of active radicals owing to increase in oxygen content with nanoparticles. These active radicals lead to formation of NO_x. However many studies have focused on control of concentration of nanoparticle in biodiesel so as to reduce the NO_x emission.[18]

Carbon Monoxide Emissions

Inclusion of alumina nanoparticle to diesel-biodiesel blends behaves as an oxidation catalyst and improves the combustion process with enhanced air fuel mixing.[19] A substantial reduction in carbon monoxide emissions has been noticed with increasing concentration of alumina nanoparticle in diesel-biodiesel blends in previous literature assigned to short ignition delay and complete combustion by the inclusion of alumina nanoparticle.[20]

Hydrocarbon Emissions

Diesel fuel and other petroleum derivatives are basically hydrocarbons. Due to incomplete combustion, unburnt hydrocarbons escape as toxic waste in the environment. On adding alumina nanoparticle in diesel and its blends, oxygen level in fuel increases thereafter encouraging complete combustion and reduces the hydrocarbon emissions whereas on increasing the dosage of alumina nanoparticle after a point reduces the carbon combustion activation which increases the hydrocarbon emission on further addition of alumina nanoparticle.

Alumina nanoparticles exhibit great possibilities to be utilized as diesel-biodiesel blends in the diesel engines due to their enhanced properties. Lately, there happen to be a finite number of researches on manufacturing, experimental investigation of properties, engine operation and the emission attributes of alumina nanoadditives.[21] Experienced effect of alumina nanoadditives addition in the diesel-biodiesel blends is listed in Table 1.[22–30]

Table 1 — Impact of alumina nanoadditives on diesel engine operation and emissions[22–30]

Reference	Fuel	Nanoadditive (in ppm)	BSFC	Efficiency/Emissions
22	Fossil Diesel	—	6% lower than that of J100A100	BTE At 20% Engine load: 11.00%
	J100 (100% Jatropha biodiesel)	—	4.5% lower than J100A100 fuel	14.52%
	J100A100	Al_2O_3 (100)	13% higher than fossil diesel	13.65%
23	B10 (10% biodiesel+90% diesel)	—	Lowered value of BSFC by 6% on average from two other samples	—
	B10E4 (4% ethanol+96% B10)	—		HC emission is much higher than B10.
	B10E4N30 (30 ppm nanoparticles+B10E4)	Carbon coated Al_2O_3 (30)		19% average drop in CO emission in contrast to B10. Average reductionof 6% in NO_X emission compared to B10. Reduced HC emissions than B10E4.
24	B20 (20% Waste cooking oil biodiesel + 80% diesel) Al_2O_3 25 ppm	Al_2O_3 (25)	Higher than neat diesel at the entire load.	Maximum BTE of 24.95% for B20 with 75ppm Al_2O_3 at full load. CO and HC emission kept decreasing at increasing dosage levels. NO_x emission increased at increasing dosage levels.
	B20 Al_2O_3 50 ppm	Al_2O_3 (50)		
	B20 Al_2O_3 75 ppm	Al_2O_3 (75)		
25	Neat diesel	—	At full load: 0.24 Kg/Kw.hr	NO_x emission at full load: 217 ppm
	B20 (20% Jatropha methyl ester and 80% of diesel fuel)	—	0.288 Kg/Kw.hr	272 ppm
	B20+20NAO	Al_2O_3 (20)	0.277 Kg/Kw.hr	250 ppm
	B20+30NAO	Al_2O_3 (30)	0.26 Kg/Kw.hr	240 ppm
	B20+40NAO	Al_2O_3 (40)	0.252 Kg/Kw.hr	230 ppm
26	D80B20 (80% diesel and 20% grape seed methyl ester)	—	Reduction in BSFC with an increase in dosing level of nanoparticles.	Increase in BTE with an increase in dosing level of nanoparticles. Reduction in NO_x emission on addition of alumina nanoparticles to blends.
	D80B20 $Al_2O_3$50	Al_2O_3 (50)		
	D80B20 $Al_2O_3$100	Al_2O_3 (100)		
	Diesel fuel	—	—	—
27	Diesel fuel +100ppm Al_2O_3	Al_2O_3 (100)	Average reduction of 7.14% in BSFC than diesel fuel	Average improvement of 5.21% in thermal efficiency than diesel fuel. Average decrease of 6.66% in NOx emission than diesel fuel.
	Diesel fuel +150ppmAl_2O_3	Al_2O_3 (150)	Average reduction of 14.06% in BSFC than diesel fuel	Average improvement of 15.91% in thermal efficiency than diesel fuel. Average decrease of 7.57% in NOx emission than diesel fuel.
28	JBD (Jatropha biodiesel)	—	At full load: 0.37 Kg/Kw.hr	BTE at full load: 24.9%; NO_x emission at full load: 1282 ppm
	JBDS15W (83% Jatropha biodiesel, 15% water, 2% surfactant)	—	0.36 Kg/Kw.hr	25.5%; 989 ppm
	JBDS15W25A	Al_2O_3 (25)	0.33 Kg/Kw.hr	27.1%; 949 ppm
	JBDS15W50A	Al_2O_3 (50)	0.32 Kg/Kw.hr	28.2%; 918 ppm
	JBDS15W100A	Al_2O_3 (100)	0.31 Kg/Kw.hr	29.4%; 870 ppm
29	DF (Diesel fuel)	—	—	—
	DF+ANOP25	Al_2O_3 (25)	Average reduction of 7% in BSFC than diesel fuel	Maximum increase of 6% in BTE than diesel fuel.
	DF+ANOP50	Al_2O_3 (50)	Average reduction of 4% in BSFC than diesel fuel	Maximum increase of 3% in BTE than diesel fuel. This blend shows lower NOx emission than other blend.
30	JBD (Jatropha biodiesel)	—	At full load: 0.37 Kg/Kw.hr	BTE at full load: 24.9%; NO_x emission at full load: 1282 ppm
	JBD50A	Al_2O_3 (50)	0.32 Kg/Kw.hr	27.9%; 1015 ppm
	JBD50CNT (with carbon nanotubes)	CNT (50)	0.33 Kg/Kw.hr	27.1%; 1001 ppm
	JBD25A25CNT	Al_2O_3 (25)+ CNT (25)	0.31 Kg/Kw.hr	28.9%; 985 ppm

Conclusions

The present literature review bestowed overview on the progress in research of alumina nanoadditives for enhancement of engine operation and reduction of emissions. The major conclusions can be summarized as that it is proved from the reported studies that these nanoadditives can enhance the engine performance with diesel, biodiesel fuels and blends. There is difference in variation of BSFC for diesel and nanoadditive blends and blends having diesel, biodiesel and nanoadditives. BSFC tends to reduce with an increase in the portion level of alumina nanoparticles in case of diesel-nanoparticle blends but in case of diesel, biodiesel and nanoadditive blends, BSFC noticed to be higher than that of fossil diesel which might be ascribed to larger content of oxygen in biodiesel and elevated reactivity of fuel mixture owing to nanoadditives as reported in the literature. In case of diesel-alumina nanoadditive blends, NO_x emissions tend to reduce with increase in dosage of nanoparticles. Whereas in case of diesel-biodiesel and alumina nanoadditive blends, addition of nanoadditives tend to produce higher NO_x emissions as compared to neat diesel.

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