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Effect of added alumina as nano-catalyst to diesel-biodiesel blends on performance and emission characteristics of CI engine

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ABSTRACT

Recent studies affirm that petro-diesel fuel properties vary by adding the biodiesel. In addition, catalysts can mix with these fuels to improve their performance and exhaust emission characteristics. In the present paper, an experimental investigation was conducted to evaluate the effects of the alumina nanoparticles as additive to B5 (95% diesel+5% biodiesel from waste cooking oil) and B10 fuel blends on the performance and emission of a CI single-cylinder engine. The alumina nanoparticles with dosages of 30, 60, and 90 ppm were used for each fuel blends. Assessed characteristics were the torque, power, brake thermal efficiency (BTE), specific fuel consumption (SFC), exhaust gas temperature (EGT), and emissions of CO, CO_2, UHC, and NO at engine speeds of 1800, 2300, and 2800 rpm. The results for optimal fuel showed the torque, power, BTE and EGT increase 5.36%, 5.36%, 10.63% and 5.80%, respectively, when compared with those of pure diesel fuel, while the SFC unlike reduces by 14.66%. The CO and UHC exhaust emissions decrease by 2.94% and 20.56%, respectively, while NO emission rises by 43.61%. It is observed a high statistical correlation between the CO-NO and CO-O_2 contents. There is a negative statistical correlation between the CO and NO emissions.

1. Introduction

Biofuels as renewable energy derived from agricultural products are considerably important for many researchers [1]. Because the use of these fuels covers a part of energy demand and reduces the greenhouse gases, air pollution, dependence on fuel imports, and cost of energy [2,3]. Biodiesel as biofuel can be extracted from the biological materials such as vegetable oils, waste cooking oils, animal fats, and waste products from plants and forests. This fuel can be used in pure or blended forms with petro-diesel fuel in transport systems, heating homes, buildings, and industrial processes. Biodiesel as an alternative petro-diesel fuel consists of the mono alkyl esters formed by a catalyzed reaction of the triglycerides in the oil or fat with a simple monohydric alcohol [4,5]. Biodiesel is similar to diesel fuel; however, it does not have unpleasant ingredients such as sulfur and polycyclic aromatics. It can be employed instead of diesel fuel without making any special modifications to the components of the combustion engines [5].

Many strategies have been adopted to reduce NO_x and soot emissions simultaneously to achieve the emission targets in common diesel engines [6,7]. Recent research has shown that using biodiesel reduces the amount of unburned hydrocarbons (UHC), carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides, and solid particles emitted from the exhaust. Only, the nitrogen oxides slightly increase that can be reduced via adjusting the timing of fuel injection [8].

Fuel economy and emission characteristics in internal-combustion engines are controlled by physical and chemical properties of the fuel. Various additives as the catalyst are used for fuels in order to improve fuel quality, achieve better combustion and reduce the exhaust emissions. Many attempts have made to increase the performance and reduce the exhaust emission by blending various alcohols and methyl esters with diesel [9–11]. On the other hand, blended catalysts accelerate the fuel instability reactions during combustion process, and promote the engine performance [12]. In recent years, nano-catalysts or nano-additives have improved the thermo-physical properties of fuels such as high

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Nomenclature

ASTM	American Society for Testing and Materials
B0	Pure Diesel
B5	95% Diesel + 5% Biodiesel
B10	90% Diesel + 10% Biodiesel
AL	Al_2O_3 nanoparticle
B5AL30	B5 + 30 ppm Al_2O_3
B5AL60	B5 + 60 ppm Al_2O_3
B5AL90	B5 + 90 ppm Al_2O_3
B10AL30	B10 + 30 ppm Al_2O_3
B10AL60	B10 + 60 ppm Al_2O_3
B10AL90	B10 + 90 ppm Al_2O_3
B20	20% Biodiesel +80% Diesel
B100	biodiesel
bmep	Brake mean effective pressure (MPa)
bTDC	before Top Dead Centre
BTE	Brake Thermal Efficiency (%)
°C	Centigrade Degree
CI	Compressed Ignition
cm	centimeter
CO	Carbon Monoxide (vol. %)
CO_2	Carbon Dioxide (vol. %)
EGT	exhaust gas temperature
G	gram
h	hour
HHV	Higher Heating Values (MJ/kg)
K	Kelvin
kg	kilo grams
kW	kilo Watt
l	liter
LHV	Lower Heating Values (MJ/kg)
Mbar	Millibar
MJ	Mega joules
mm	millimeter
mPa.s	mega Pascal second
Mol	mole
MSDS	Material Safety Data Sheet
Nm	Newton meter
NO	Nitrogen Oxides (ppm)
O_2	Oxygen (vol. %)
ppm	part per million
rpm	Revolutions per minute
s	second
SFC	Specific Fuel Consumption (g/kWh)
UHC	Unburned Hydrocarbons (ppm)
US	United States
vol	Volume
wt	weight

surface area-to-volume ratio, thermal conductivity, and mass diffusivity. Based on the literature review, it has been found that nano-additives as well as biodiesel enhance the flash point, fire point, kinematic viscosity, and other characteristics when blended with diesel fuel [13]. Most nanoparticles are made of ceramic, metallic, and polymeric materials. The most common nanoparticles are ceramics and metal oxides such as titanium, carbon, aluminum, and iron [14]. Large surface and high energy level increase the catalytic performance of metal nanoparticles [15].

Many studies have been conducted in terms of fuel additives and their effect on the engine combustion, performance, and emission characteristics [9]. For example, Shaafi and Velraj studied the combustion, performance, and emission characteristics of an engine fueled with two modified fuel blends, B20 (diesel-soybean biodiesel) and D80SBD15E4S1 (diesel-soybean biodiesel-ethanol blends), with alumina (Al_2O_3) as a nano-additive. The cylinder pressure arising from combustion and the heat release rate were higher than those of diesel fuel. The presence of oxygen in the soybean biodiesel and the better mixing capabilities of the nanoparticles reduce the CO and UHC. The NO_x slightly rose at full load condition [16]. Gumus et al. examined the effects of alumina and cupric oxide (CuO) nanoparticles added to diesel fuels. The effects of the additives on the engine performance and emission were also investigated. The storage and combustion characteristics were improved by adding the nanoparticles. Engine torque and brake power output values were slightly increased by addition of alumina and cupric oxide to pure diesel [17]. In another study, Guru et al. empirically examined the effects of adding magnesium, manganese, calcium, and copper in diesel fuel on emission, efficiency, and quality of fuel ignition. They also studied the levels of pollutants like SO_2, CO_2, and CO and cetane number of fuel in two cases of the additives' diesel and pure diesel [18].

Srinivasa and anand were investigated the performance and emissions of a CI engine fueled by Jatropha based biodiesel. They were improved fuel characteristics using alumina hydroxide (AlO(OH)) nanoparticles as a fuel additive with dosage of 25, 50 and 100 ppm in a set of biodiesel emulsion fuels (BD5W: Blend of 93% biodiesel + 1% Span80 + 1%Tween80 + 5% water, and BD10W: Blend of 88% biodiesel + 1% Span80 + 1% Tween80 + 10% water). The analysis showed that the brake thermal efficiency was lower, and NO level in the engine exhaust was higher for the biodiesel compared with pure diesel. However, the performance and emission characteristics were enhanced with adding of water and nanoparticles [19].

Sajith et al. studied the effects of cerium oxide (CeO_2) nanoparticles as additive to biodiesel on engine performance, chemical-physical properties of the fuel, and emission resulting from the fuel combustion. They were applied different cerium oxide dosages of 20, 40, 60, and 80 ppm to achieve the optimal blend. The results indicated that the flash point and viscosity of the biodiesel increase by adding the cerium oxide nanoparticles. The values of NO_x and UHC emissions are greatly reduced [20]. Ganesh et al. examined the effects of cerium oxide nanoparticles (the size ranging from 10 to 20 nm) as additives to Jatropha biodiesel on reducing emissions of CI engine. The flash point, volatility, and viscosity of biodiesel increased after the addition of the cerium oxide nanoparticles [21].

Bhagwat et al. examined the graphene nanoparticles added to diesel-biodiesel blends at dosage of 25 and 50 ppm in a CI single-cylinder engine [22]. Fengsvanarak et al. improved the performance and exhaust emissions of the engine fueled with palm biodiesel and nano-titanium dioxide (TiO_2) as additive. The quality of nano-fuels was enhanced by 0.1%. Furthermore, the kinematic viscosity was reduced, and the cetane number was increased [23].

D'Silva et al. used titanium dioxide (TiO_2) nanoparticles as an additive to conventional diesel fuel in a CI engine. Density, fire point, viscosity, and calorific value of nano-diesel were experimentally determined. It was observed that the properties of diesel fuel improved by adding the titanium dioxide nanoparticles [24].

In many countries such as Iran, the production and use of biodiesel recently has started. Still, the possible for use of higher dosages of biodiesel blended with diesel fuel in many countries is not existed. Long-term strategy of many Asian countries spatially