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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

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HIGHLIGHTS

- Biodiesel acts as bridging agent in Diesterol fuel blend.
- Cerium Oxide Nanoparticles and Carbon Nanotubes are used as fuel borne catalysts.
- Nanoparticles in Diesterol significantly improves engine performance & reduce smoke.

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ABSTRACT

An experimental investigation is carried out to establish the performance, combustion and emission characteristics of a variable compression ratio engine using Cerium Oxide Nanoparticles and Carbon Nanotubes as fuel-borne nanoparticles additives in Diesterol (diesel–biodiesel–ethanol) blends. As Diesel and Ethanol are immiscible, Castor oil biodiesel is used as an additive which acts as a bridging agent to prevent the phase separation. Stability studies are carried out using Cerium Oxide Nanoparticles (CERIA) and Carbon Nanotubes (CNT) each 25, 50, 100 ppm in the Diesterol blends subjected to high speed mechanical agitation followed by ultrasonic bath stabilization. It is observed that the blends are stable which are suitable for performance test on the compression ignition engine. Studies on the performance, combustion and emission characteristics are carried out on a variable compression ratio engine using the stable Diesterol–CERIA–CNT blends under various loading conditions at an optimum compression ratio of 19:1 to estimate the emission reduction potential of CERIA and CNT as catalyst in Diesterol blends. The addition of CERIA and CNT in Diesterol blend increases the cylinder gas pressure when comparing with the neat Diesterol blends. The Carbon Nanotubes act as a catalyst to accelerate the burning rate which results in decreased ignition delay and cause for the lower heat release rate and advancement of the peak heat release rate. The Cerium Oxide Nanoparticles act as an oxygen donating catalyst which provides oxygen for the oxidation of carbon monoxide and absorbs oxygen for the reduction of nitrogen oxides. The activation energy of Cerium Oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and helps to prevent the deposition of non-polar compounds on the cylinder wall resulted in significant reduction of hydrocarbon and smoke emissions. The combined effect of CERIA and CNT as fuel-borne nanoparticles additives in the Diesterol fuel blend contributes for the cleaner combustion and significantly reduces the harmful exhaust gas emissions.

1. Introduction

The growing need to reduce the environmental impact of the modern life style imposes a continuous development of novel technologies aimed at severe reduction of pollutant emissions. Diesterol blends are formulated in the recent years, which not only serve for the utilization of ethanol in CI engines, also to reduce the harmful pollutant emissions when comparing with the neat diesel [1]. In view of utilizing ethanol in compression ignition engines, Lapuerta et al. [2] studied the stability of the diesel–biodiesel–ethanol blends at different temperatures and found that the biodiesel acts as a stabilizer component in the e-diesel blends except at low temperatures, where it favors the formation of a gelatinous phase. The engine performance test results with diesel–biodiesel–ethanol

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Nomenclature

CERIA	Cerium Oxide Nanoparticles
CI	Compression Ignition
CNT	Carbon Nanotubes
D+CNT 25	Diesel+ 25 ppm of Carbon Nanotubes
D+CERIA 25	Diesel+ 25 ppm of Cerium Oxide Nanoparticles
E20	70% Diesel+ 10% Biodiesel+ 20% Ethanol (D70B10E20)
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
W/D	Water + Diesel
XRD	X-ray Diffraction

blend showed increased hydrocarbon emission with increase in ethanol concentration and a significant reduction in smoke and particulate emissions when compared with the neat diesel. Park et al. [3] investigated the mixing stability, fuel properties and spray atomization characteristics of diesel–biodiesel–ethanol blends. They found that the biodiesel prevents phase separation of ethanol–diesel blend and the higher ethanol blends induces decrease in droplet size distribution of the fuel blends. Lapuerta et al. [4] studied the lubricity of ethanol–biodiesel–diesel fuel blends using a high frequency reciprocating test rig at different temperatures and found that the incorporation of ethanol did not result in significant losses of lubricity until the ethanol concentration close to 100%. Also the increasing temperature of the blend led to improved lubricities as a consequence of the ethanol evaporation from the lubricating layer. Hadi et al. [5] conducted experiments to found a suitable low cost and renewable additive for the ethanol–diesel blend and formulated Diesterol, a mixture of fossil diesel fuel, vegetable oil methyl ester and plant derived ethanol to reduce the engine exhaust emissions. It was observed that the emissions such as nitrogen oxides, carbon monoxides, hydrocarbon and smoke were reduced by increasing the bio-fuel composition of Diesterol throughout the engine operating range. The variable compression ratio engine technology is capable of handling any fuel with wide range of fuel properties. Arul Mozhi Selvan et al. [6–9] carried out experimental investigations to study the performance, combustion and emission characteristics of Diesterol fuel blend and compared with the neat diesel in a direct injection compression ignition engine under the compression ratios of 15:1, 17:1 and 19:1 at a constant speed of 1500 r/min. They found that the biodiesel can be reliably used as an additive in diesel–ethanol blends to improve the blend stability, fuel economy and lesser emissions.

Among the various techniques available to reduce the harmful exhaust gas emissions, the use of fuel-borne catalysts are currently focused due to the advantage of fuel efficiency while reducing the harmful greenhouse gas emissions, nitrogen oxides and particulate matter. The Cerium Oxide Nanoparticles act as a catalyst in the reduction of toxic gases on the combustion of hydrocarbon fuel and improves the fuel economy. The amount of oxygen reversibly provided in and removed from the gas phase is called Oxygen Storage Capacity (OSC) of CERIA and the presence of CERIA in the fuel helps to regenerate a diesel particulate filter at lower temperatures [10]. Heejung et al. [11] studied the influence of Cerium Oxide additive on ultrafine diesel particle emissions and kinetics of oxidation. They found that the addition of CERIA to diesel causes significant reduction in number weighted size distributions and light-off temperature and an increase in the oxidation rate as observed by Nubia et al. [12]. The studies on the complexity of the ethanol reactions on the surfaces of noble metals/Cerium Oxide catalysts revealed that the Cerium Oxide Nanoparticles can be used as a fuel-borne additive in the hydrocarbon liquid fuels to promote complete combustion and to reduce the exhaust emissions significantly [13]. Arianna et al. [14] investigated the potential of emission reduction of an experimental 6% W/D emulsion with EURO-3 LD diesel vehicles in comparison to a commercial 12% W/D emulsion with a EURO-3 HD engine with a Cerium based additive and found a significant reduction in PM and the associated PAH. Sajith et al. [15] conducted an experimental investigation to find the influence of Cerium Oxide Nanoparticles on the major physico-chemical properties and the performance of a CI engine with the dosing levels from 20 to 80 ppm in biodiesel. They found that the addition of Cerium Oxide Nanoparticles increase the flash point and kinematic viscosity of the biodiesel. In addition, they observed a significant improvement in engine efficiency and reduction of hydrocarbon and nitrogen oxides emissions by 40% and 30% respectively. The Cerium Oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of carbon monoxide and absorbs oxygen for the reduction of nitrogen oxides. The activation energy of Cerium Oxide acts to burn-off the carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall which resulting in the reduction of hydrocarbon emissions. The key to use CERIA for catalytic purpose is the low redox potential between the Ce^{3+} and Ce^{4+} ions (1.7 V) that allows the following reaction to easily occur in the exhaust gases.

$$2CeO_2 \leftrightarrow Ce_2O_3 + 1/2O_2 \quad (1)$$

Hydrocarbon combustion:

$$(2x+y)CeO_2 + CxHy \rightarrow \left\{\frac{(2x+y)}{2}\right\}Ce_2O_3 + \frac{x}{2}CO_2 + \frac{y}{2}H_2O \quad (2)$$

Soot burning:

$$4CeO_2 + Csoot \rightarrow 2Ce_2O_3 + CO_2 \quad (3)$$

Cerous oxide (Ce_2O_3) formed from the oxidation of hydrocarbon gets re-oxidized to Cerium Oxide (CeO_2) through the reduction of nitrogen oxide.

$$Ce_2O_3 + NO \rightarrow 2CeO_2 + 1/2N_2 \quad (4)$$

The most eye-catching features of the Carbon Nanotubes are their electronic, mechanical, optical and chemical characteristics, which opened a way to the future applications. In the present work, the Carbon Nanotubes are used as a fuel-borne additive to enhance the combustion characteristics of the fuel and to reduce the level of harmful pollutants in the exhaust emissions. The Carbon Nanotubes have the ability to trap the free radicals and the carbon fibrils can function as an anti-knock additive. The carbon fibrils can be used as sequestering agents for tramp metals/tramp ions present in the engine fuel to reduce the formation of insoluble complexes, results in fewer insoluble impurities. Also, the addition of Carbon Nanotubes in diesel increases the cetane number of the blend and acts as a catalyst to accelerate the burning rate [16]. As the diesel soot can be recycled as a carbon source for synthesizing of Single-Wall Carbon Nanotubes (SWNTs) through the laser vaporization technique, the SWNTs produced in this way provide economic benefits and also contribute to a cleaner environment [17].

The compression ignition engine can be fuelled with the maximum of 20% Ethanol for producing better performance and