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Effect of carbon coated aluminum nanoparticles as additive to biodiesel-diesel blends on performance and emission characteristics of diesel engine☆

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HIGHLIGHTS

- Stable fuel blends of diesel-biodiesel-ethanol-Al@C nanoparticles are prepared.
- Improvement of engine performance is observed with lowered BSFC by 6%.
- NOx emission is improved with an average drop of 6%.
- The CO emission can be significantly reduced by 19% on average.
- PN is increased obviously on the presence of Al@C nanoparticles.

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ABSTRACT

This study investigates the effects of carbon coated aluminum (Al@C) nanoparticles added to diesel-biodiesel blends as additives on engine performance and emissions. The Al@C nanoparticles are added into the diesel-biodiesel fuel in the mass fractions of 30 ppm under ultrasonic mixing. The experimental tests are conducted using a Cummins diesel engine. For comparison, three kinds of fuels including diesel-biodiesel blend (B10), B10 with 4% ethanol (B10E4), and B10 with 4% ethanol and 30-ppm nanoparticles (B10E4N30) are used for the tests under the European Stationary Cycle (ESC). The results show clearly that adding Al@C nanoparticles can reduce brake specific fuel consumption (BSFC) by 6% on average; along with a drop of 6% in NO_X emission and CO emission is reduced by 19%, comparing with B10. However, the presence of ethanol in fuel blend increases THC emission. Nevertheless, addition of Al@C nanoparticles reduces THC emission by 14.5% compared with B10E4. The emission of particles number (PN) is increased by 2.2 times for B10E4N30 on average but is reduced by 11.8% for B10E4 (adding ethanol only) on the contrary, compared to B10. The studies on morphology and phase structure of nanoparticles after combustion indicate that Al@C nanoparticles have been transformed into alumina nanoparticles.

1. Introduction

Confronted with the increase demand for more vehicles and the challenges to reduce energy/fuel consumption and emissions from engines to meet the stricter emission legislations, vehicle and engine manufacturers have been working hard on improving efficiency of energy use and reducing pollutant emissions in the last decades. There are three main methods for improving engine performance in terms of energy utilisation efficiency and reducing emissions: modification of combustion system, developing and using renewable alternative fuels and improving treatment of exhaust gases. Pirouzfar et al. pointed out exhaust emissions arising from the fuel could be controlled by blending an oxygenated fuel (such as Methanol, Ethanol, and *n*-Butanol) with the diesel fuel, and engine performance could be improved at the same time [1]. A lot of research recognizes that adding biofuels can reduce some emissions with no or minor impact on engine performance, especially biodiesels [2,3]. Moreover, some researches reveal that adding various nanoparticles as nanocatalysts or nanoadditives in diesel or biodiesel-diesel blends can increase energy utilisation efficiency of engines by improving combustion efficiency and reduce exhaust emissions [4,5]. The most common nanoparticles used are metal and metal oxides, including aluminum, iron and silver [6–8], alumina [9–11], zinc oxide [12,13], titanium oxide [14,15], cerium oxide [16,17], iron oxide [18,19], and carbon nanotubes [20,21]. Some used are other kind of

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Nomenclature

Al@C	carbon coated aluminum
B10	10% biodiesel + 90% diesel
B10E4	4% ethanol + 96% B10
B10E4N30	30 ppm nanoparticles + B10E4
BSFC	brake specific fuel consumption
EDX	Energy Dispersive X-ray Spectroscopy
EUE	energy utilisation efficiency
NO_X	nitrogen oxide
THC	total hydrocarbon compounds
XPS	X-ray photoelectron spectroscope
B20	20% biodiesel + 80% diesel
B50	50% biodiesel + 50% diesel
B100	100% biodiesel
BMEP	brake mean effective pressure
CO	carbon monoxide
ESC	European Stationary Cycle
HRTEM	high-resolution TEM
SEM	scanning electron microscopy
TEM	transmission electron microscopy
#	number of particles

nanoadditives, such as cerium oxide nanoparticles and carbon nanotubes as mixed additives [22], cerium oxide with ferrocene nanoparticles [23], amorphous Ti–Al–B mixed metal nanopowders [24], manganese oxide [25], copper oxide [25] and nano-organic additives [26]. All these nanomaterials have been found being very useful to act as combustion catalyst to improve combustion behavior and reduce pollutant emissions because of their multifold enhancement in thermophysical and chemical properties of the modified fuels such as high surface to volume ratio, high reactive medium for combustion, high thermal conductivity to enhance heat and mass transport, improvement in flash point and so on [5].

On the other hand, core-shell structure nanoparticles, such as carbon coated metal or alloy nanoparticles have been attracted more and more research interests due to their unique structure [27,28]. Carbon coatings can not only protect metal core in ambient conditions and maintain excellent thermal properties, but also improve stability of suspension fuel because of its better hydrophilia than metals and metal oxides. However, few studies are found using carbon-coated-metal nanoparticles as additives. Therefore, it is necessary to carry out an investigation to study and understand the effect of adding carbon-coated-metal nanoparticles into diesel fuel blends on improving the energy utilisation efficiency (EUE) of engines and exhaust emissions. Due to Al or Al_2O_3 nanoparticles have been studied widely as fuel nanoadditive and show excellent ability on enhancement of EUE of engines as well as emission characteristics [6,7,9–11], and it is known that aluminum has better thermal conductivity and lower density than most other metals which is beneficial to fuel suspension stability, carbon-coated-aluminum nanoparticles are selected as additive in this study.

2. Experimental method

Biodiesel-diesel blends with various concentration of palm oil methyl ester (10, 20, 50 and 100% respectively) were selected as base fuels and named as B10 (10% biodiesel + 90% diesel), B20 (20% biodiesel + 80% diesel), B50 (50% biodiesel + 50% diesel) and B100 (100% biodiesel). As nanoparticles tend to disperse homogenously in ethanol, a small certain amount of carbon coated aluminum (Al@C) nanoparticles at a dosage of 30 ppm in mass fraction was dispersed in ethanol solution using ultrasonic bath for 30 min first. Then obtained nanoparticles-ethanol suspension was mixed with biodiesel-diesel blends under ultrasonic treatment for another 15 min at volume ratio of 4:96, without adding any surfactants. The morphologies and microstructures of Al@C nanoparticles before and after engine test was examined by transmission electron microscopy (TEM, JEOL JEM-2010HR) with energy dispersive X-ray spectroscopy (EDX, Thermo scientific ultra dry), X-ray photoelectron spectroscope (XPS, K-Alpha Thermo scientific) and field scanning electron microscopy (SEM, JEOL JEM-2100F). For comparison, B10 blend fuel with 4% ethanol was also prepared without adding nanoparticles, which was named as B10E4 (4% ethanol + 96% B10).

The equipment and facilities used for the engine test included engine-performance test bench, exhaust gas analysers and a special

Table 1
Engine specifications.

Type	Cummins, four-cylinder, four-stroke diesel engine
Power (PS)	207
Peak torque (Nm)	760
Governed speed (rpm)	2500
Displacement (L)	4.5
Bore (mm)	107
Stroke (mm)	124
Cylinders	4
Emission	Euro 5
Injection system	Common rail
Aspiration	Turbo-charged
Emission standard	Euro 5

designed filter rig to collect the particulates emitted from the engine. The engine performance, emission concentrations and the results of burned particles were recorded from their own data acquisition system. A heavy-duty diesel engine (Cummins ISBe5, it is an engine of four-cylinder in line, four-stroke with displacement of 4.5 L) was used to carry out the tests to investigate the effect of target fuel blends. The engine parameters are listed in Table 1 in detail.

The engine had a common rail fuel injection system, which had a maximum value of 1800 bar pressure and one solenoid injectors for each cylinder, was shown in Fig. 1. The engine test-bench, the emission

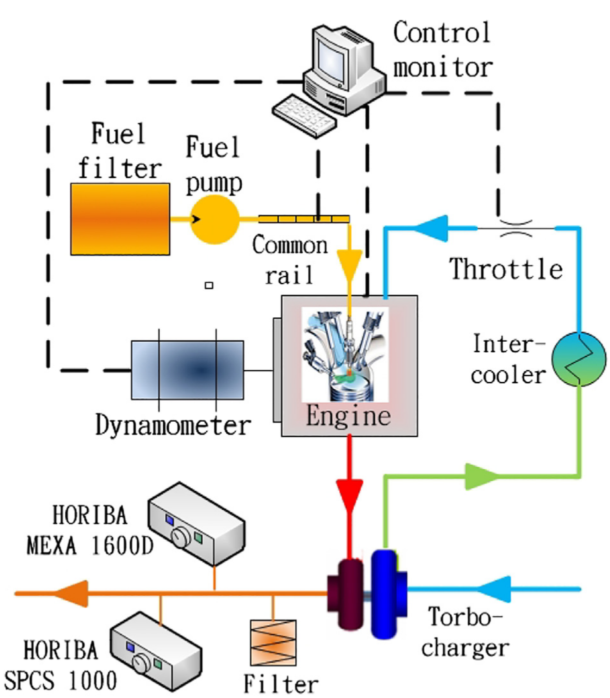

Fig. 1. Schematic diagram of engine test bench.