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Diesel engine combustion characteristics using nano-particles in biodiesel-diesel blends

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ABSTRACT

The current experimental research study focuses on influence of CNT and Ag nano-particles on combustion parameters of diesel engine. The based fuel used is blend of biodiesel and diesel. Nano-particles were synthesized, characterized by TEM and XRD analysis and blended with biodiesel-diesel blends at a fraction of 40–120 ppm using ultrasonicator. Experimental results indicated that by adding nano additives to diesel-biodiesel blends, peak pressure of in–cylinder gases and the peak pressure rise rate increase in comparison with neat diesel fuel due to the shorter ignition delay resulting in earlier combustion duration and higher maximum cylinder pressure. It can be found that the heat release rate of the diffusion combustion phase is higher for biodiesel and biodiesel with nano additives when compared with that of neat diesel fuel due to the higher oxygen content of the blended fuels that have improved the diffusion combustion phase and decreased the combustion duration. Peak pressure was increased up to 15.38% in BD + CNT120 (Biodiesel + 120 ppm Carbon Nano Tubes nano additive). The innovated fuel blend also increases peak pressure rise rate and heat release rate by up to 23.33% and 28% respectively. Ignition delay was decreased 8.98% in BD + CNT120 compared to neat diesel fuel.

1. Introduction

The addition of nano particles to diesel fuel has been done by various researchers for the improvement of performance and reduction of emissions in diesel engine. To improve the performance of the biodiesel and ethanol blend, addition of ZnO nano particle study has been conducted [1]. Kumar et al., [2] investigated the effect of diesel water emulsions and nanotechnology in diesel engine. The addition of nanofluids decreased the emission parameter and there was an improvement in combustion efficiency. BTE, NOx and smoke was increased with using of zinc oxide nano materials as additive to diesel fuel [3]. Addition of zinc oxide nano particles in palm oil biodiesel, increased the BTE, NOx, EGT and decreased in emissions of CO, HC and smoke [4,5]. The influence of alumina and silica nano particles in butanol-diesel blends increased diesel engine performance, decreased in emissions of soot and increased in CO and NOx compared to diesel fuel [6]. The effect of addition of Zinc Oxide nano particles to diesel blends has been investigated, the results of this research study showed that heat release rate and BTE increased with increase in ZnO nano particles in the fuel [7,8].

It was observed the CNTs added to diesel-biodiesel fuel blends enhanced in power (3.67%), BTE (5.57% and EGT (5.57%). SFC, CO, UHC and soot reduced and NOx emissions increased [9]. Nano-additives in fuels have improved the thermo-physical properties such as high surface area-to-volume ratio, thermal conductivity. It has been found that nano-additives along with diesel, biodiesel and their blends enhanced the flash point, fire point and kinematic viscosity [10,11]. Adding the synthesized magnesium, manganese, calcium and copper to diesel fuel decreased the levels of pollutants like SO_2, CO_2, CO [12]. Alumina oxide (Al_2O_3) and cupric oxide (CuO) nanoparticles added to diesel fuels and combustion characteristics were improved by using nanodiesel blended fuels [13]. The effect of 25 ppm Al_2O_3 nano additive in biodiesel-diesel-ethanol blend at original timing of 23 deg bTDC, advanced timing of 27 deg bTDC and retarded timing of 19 deg bTDC were experimented in a diesel engine. Al_2O_3 addition at ADV IT resulted in higher peak pressure and heat release rate occurring nearer to TDC, higher HC, CO, NOx and lower ignition delay. Whereas, Al_2O_3 addition in RET IT causes lower cylinder pressure and heat release away from TDC [4]. The effects of adding Multi-Walled Carbon nanotubes (MWCNTs) to Jojoba methyl ester diesel blended fuel on performance and emissions of a CI engine has been investigated. The MWCNTs-B20D blended fuel attained a maximum increase of 16% in the brake thermal efficiency and a decrease of 15% in the brake specific fuel consumption compared to the neat diesel fuel. The peak cylinder pressure, the maximum rate of pressure rise and the peak heat release rate were increased by 7%, 4% and 4% respectively. NOx, CO and UHC were reduced by 35%, 50% and 60%, respectively [5,6]. Vibration signatures has been recorded with 100 ppm concentration of ZnO particles of 20

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and 40 nm sizes suspended in Jatropha methyl Ester biodiesel along with hydrogen as secondary fuel. It has been proved that the best fuel blend with least vibration is B30 and B20 with nano particle of size 40 nm for hydrogen flow rate of 0.5, 1.0 and 1.5 l/min [7,8]. The high surface area of soluble nano-sized catalyst particles resulted in significant overall improvements in the combustion reaction, all pollutants were reduced and engine power and torque increased 7.81% and 4.91%, respectively, and fuel consumption decreased by 4.50% [9]. The use of MWCNTs is found to improve all engine performance parameters and reduced emissions. NO_x decreased by 45%, CO by 50% and UHC by 60%. Cylinder peak pressure increased about 7%. The dose level of 40 mg/l was found the best level to improve the engine performance [10]. The cylinder pressure during the combustion and the heat release rate are higher in the biodiesel-diesel with nano alumina fuel blend, compared to neat diesel fuel. The exhaust gas temperature is reduced and brake thermal efficiency increased in the case of fuel blend. The presence of oxygen in the soybean biodiesel, and the better mixing capabilities of the nano-particles reduced the CO and HC appreciably, though there is a small increase in NO_x at full load condition [11]. The cerium oxide nanoparticles act as an oxygen donating catalyst which provides oxygen for the oxidation of CO and absorbs oxygen for the reduction of NO_x. The emission levels of hydrocarbon and NOx are reduced with addition of cerium oxide nano particles. The results showed an improvement in brake thermal efficiency, a reduction of brake specific fuel consumption and emission level due to better air/fuel mixing and fast evaporation [12,14–22].

The influence of cerium oxide additive on ultrafine diesel particle emissions and kinetics of oxidation was studied by Jung et al. [23,24]. It has been detected that addition of cerium to diesel cause significant reduction in number weighted size distributions and light-off temperature and the oxidation rate was increased significantly. The structural and morphological characterization of a Ce-Zr mixed oxide supported Mn oxide as well as on its catalytic activity in the oxidation of particulate matter arising from diesel engines has been studied by Escribano et al. [25]. Mn-Ce-Zr catalyst shows high activity in the soot oxidation producing CO_2 and CO as a byproduct in the range 425–725 °K. Idriss investigated the complexity of the ethanol reactions on the surfaces of noble metals/cerium oxide catalysts [26]. The hazard and risk assessment with the use of nano-particle cerium oxide bases diesel fuel was studied by Barry Park et al. [27]. Effects of cerium oxide nano-particles addition in diesel and diesel-biodiesel-ethanol blends on performance and emission characteristics of a CI engine has been studied and results showed that the cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall results reduction in HC emissions. The tests revealed that cerium oxide nano-particles can be used as additive in diesel and diesel-biodiesel-ethanol blend to improve complete combustion of the fuel and reduce the exhaust emissions significantly [23]. Carbon nanotubes (CNTs) are as useful additives for increasing the octane number. Functionalized carbon nanotubes containing amide groups have a high reactivity and can react with many chemicals. These compounds can be solubilized in gasoline to increase the octane number. In a study, the amino-functionalized carbon nano-tubes were added to gasoline. Research octane number analysis showed that these additives increase octane number of the desired samples [28].

Several research studies have been carried out on the effects of nano-biodiesel blended fuels on the performance and emission characteristics of diesel engine. The literature reviews show that no research have been reported on combustion parameters of diesel engine using carbon nano tubes (CNTs), Ag nanoparticles, biodiesel and its blends with pure diesel fuel, consequently, in this present experimental work, the effect of CNTs and Ag nano additives in biodiesel and diesel blends were investigated in a diesel engine. The combustion activity of nanoparticles has been analyzed in terms of cylinder pressure, heat release rate, ignition delay, performance and emission parameters.

Table 1
Main characteristics of the test engine.

Engine Type	CI engine, 6 Cylinder, 4 – stroke, water cooled
Combustion Order	1-5-3-6-2-4
Bore × Stroke (mm)	98.6 * 127
Displacement Volume (Lit)	5.8
Max. Torque (N.m/rpm)	410/1300
Max. Power (kW/rpm)	82/2300
Fuel injector type	Single hole nozzle with hole diameter of 0.2 mm and spray cone angle obtained ranges from 5 to 20 degree
Injection pressure	150–180 bar
The shape of combustion chamber	Shallow depth chamber
Fuel injection system	Naturally aspirated, direct injection; solid and mechanical injection with distributer system

2. Experimental work

2.1. Experimental setup

Considering the accomplished researches about nano fuels and diesel fuel nano additives, two silver nano-particles (Ag) and carbon nano tubes (CNT) were applied as nano additives to these fuels. The performance tests for the diesel-biodiesel blends and neat diesel with nano silver and CNT nano particles as fuel-borne catalyst additive are carried out on a computerized diesel engine. In this study, the experiments were performed on a CI engine naturally aspirated, direct injection; fuel injection system of engine was solid and mechanical injection with distributer system. The shape of combustion chamber was Shallow depth chamber. Fuel injector type was single hole nozzle with hole diameter of 0.2 mm and spray cone angle obtained ranges from 5 to 20 degree, it requires high injection pressure in the range of 150–180 bar. The engine specification is given in Table 1. A 190 kW SCHENCK-WT190 eddy–current dynamometer was used in the experiments. Fuel consumption rate was measured in the range of 0.4–45 kg/h by using laminar type flow meter, Pierburg model. The measuring precision error for the calibration factors was ± 0.1%, according to the DIN 1319 standard. The confidence level for this model was around 95%. Air consumption was measured using an AVL Flowsonix air flow meter. The measurement range was 0… ± 1400 kg/h, with the error of < ± 1%. The relative air–fuel ratio, the emission parameters and the exhaust gas temperature from an online and accurately calibrated exhaust gas analyser DIGAS4000 were recorded. The emission parameters from an online and accurately calibrated exhaust gas analyser DIGAS 4000 were recorded. AVL DIGAS analyzer is used to measure the exhaust constituents such as CO, HC and NO_x. The sensitivity and the measurement accuracy of the instruments used for measuring the exhaust gas concentration have been listed in Table 2. The testing temperature was controlled, and temperature measurement accuracy was ± 1 °C. By using the root-sum-square method, the percentage uncertainties in measuring various parameters were determined. Fig. 1 shows the experimental setup. All experiments have been carried out full load condition to the maximum amount of fuel injected.

The properties of the produced Biodiesel in comparison with the ASTM D6751 standard are described in Table 3. Also the use of carbon nano tubes (CNT) and silver nano particles in neat diesel and diesel-biodiesel blend has the tendency to settle down at the fuel tank. Silver nano particle with the size of 50 nm and CNT nano particle with the diameter of 5 nm are used in the test. After series of experiments, it is found that the blends subjected to high speed blending followed by ultrasonic bath stabilization improves the stability. Vegetable methyl ester (Biodiesel) prepared from the waste cooking oil (WCO) through transesterification process (Fig. 2), and then blended with diesel fuel. A