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Full Length Article

The effect of Aluminum oxide nanoparticles addition with Jojoba methyl ester-diesel fuel blend on a diesel engine performance, combustion and emission characteristics

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ABSTRACT

In the current work, an experimental investigation was conducted to recommend the optimal concentration of alumina nanoparticles (Al_2O_3) into Jojoba biodiesel-diesel (JB20D) fuel blend at which the best diesel engine performance and exhaust emissions were attained. The Al_2O_3 nanoparticles with concentrations varied from 10 to 50 mg/l by step of 10 mg/l were mixed into JB20D fuel blend with the help of ultrasonic stabilization. The results of the present study revealed that JB20D slightly reduced the engine performance and increased its emission characteristics at all engine tested operating conditions as compared to pure diesel oil. Utilizing of Al_2O_3 additives was found to improve all engine performance characteristics. However, the best emission characteristics were obtained at the dose level of 20 mg/l, where remarkable emissions reduction were observed; NO_x by 70%, CO by 80%, UHC by 60%, and Smoke opacity by 35%. While the best of both mechanical performance and engine combustion characteristics were achieved at a concentration of 40 mg/l, where the reduction in the brake specific fuel consumption – bsfc was by 12% and increase in the cylinder peak pressure – p_{max}, the maximum rate of pressure rise – $dp/d\theta_{max}$, and maximum rate of gross heat release – $dQ_g/d\theta_{max}$ were 4.5%, 4%, and 4%, respectively. According to the comparisons of engine performance and emissions, the recommended concentration of Al_2O_3 in JB20D blends was concluded to be 30 mg/l, which gave remarkable enhancement in all engine performance parameters.

1. Introduction

Compression ignition engines play a substantial role in transportation, locomotives, irrigation sector and industrial sectors due to their simplicity of operation, high reliability, durability and well-established design. On the other hand, diesel engines are considered one of the primary sources of many toxic emissions, especially, the particulate matter (PM), and nitrogen oxides (NO_x) which have hazardous environmental impacts. These toxic compounds cause the formation of acidic rains, the depletion of ozone layer, the increase of greenhouse phenomena, the formation of smog, and undesirable climatic changes [1–3]. There are essential approaches to reduce diesel emissions; including engine design modifications, engine combustion enhancement, and the use of exhaust gas treatment tools [4]. The modification of engine combustion seems to be the most recommended because it may need only minor changes to engine systems rather than the use of new designs or the use of additional systems. This approach is realized by regulating the fuel properties, modifying fuel injection, and use of fuel additives [4,5]. In this regard, the use of oxygenated fuels as biodiesel is found to be a promising alternative to substitute the conventional diesel fuel. Thus, the alternative fuels would depend on renewable resources. Currently, the most promising renewable fuel resource is the use of biomass to produce the commonly called biofuels. On the other hand, to completely overcome additional problems related to food requirements around the world, the proposed biomass resources shall be non-edible [4,6]. The most recommended non-edible oils are those generated from plants that do not need a significant amount of water or can grow in the barren lands using waste-water [4,6,7]. These generated fuels will support nations to reduce the import of fossil fuels or extend the time until the depletion of the current fuel reserves [4].

Jojoba is a name that is becoming increasingly common as an industrial crop in several countries. In recent years, Jojoba oil has become the most genuinely Egyptian product [8]. Jojoba plant is one of the promising non-edible plants growing in the desert. Also, its seed has more than 50% of its weight as raw oil. Thus, raw Jojoba oil would be suitable feedstock for biodiesel production. Furthermore, the choice of

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Nomenclature

ASTM	American Society for Testing and Materials
ATDC	after top dead center
CA	crank angle, degree
CO	carbon monoxide, ppm
D100	pure diesel oil
EGT	exhaust gas temperature, °C
EVC	exhaust valve closed
EVO	exhaust valve opened
h_c	heat transfer coefficient, $w/m^2.k$
IVC	inlet valve closed
Al_2O_3	Aluminum oxide
JME	Jojoba methyl ester
JB20D	blended fuel containing 20% JME + 80% D100
JB20D10A	blended fuel (JB20D) + 10 mg/l of Aluminum oxide
JB20D20A	blended fuel (JB20D) + 20 mg/l of Aluminum oxide
JB20D30A	blended fuel (JB20D) + 30 mg/l of Aluminum oxide
JB20D40A	blended fuel (JB20D) + 40 mg/l of Aluminum oxide
JB20D50A	blended fuel (JB20D) + 50 mg/l of Aluminum oxide
N	engine speed, rpm
NO_x	nitrogen oxides, ppm
p	instantaneous cylinder pressure, bar
T	mean gas temperature, K
T_w	wall temperature, K
UHC	unburned hydrocarbons, %
V	instantaneous cylinder volume, m^3
$dp/d\theta$	pressure rise rate per crank angle, bar/deg.
$dV/d\theta$	volume rise rate per crank angle, m^3/deg.
$dQ_g/d\theta$	gross heat release rate per crank angle, J/deg.
θ	crank angle, deg.
γ	specific heat ratio

the Egyptian Jojoba oil (GREEN GOLD) is due to its availability in Egypt, its low price, and its low chemical reactivity [8,9]. From the literature, most of the studies used various methods for extraction of Jojoba oil from the seeds [10]. Those techniques are mainly mechanical pressing, mechanical pressing followed by solvent extraction, or solvent extraction only. Jojoba oil is primarily composed of straight-chain wax esters in the range of C_{26}–C_{48} with two double bonds, one at each side of the ester bond. It is not a triglyceride, making Jojoba and its derivative Jojoba esters more similar to sebum and whale oil than traditional vegetable oils [11]. The raw Jojoba oil is converted into biodiesel via transesterification process to receive Jojoba Methyl Ester (JME). It has many advantages as it performs under normal conditions and yields better quality biodiesel [11].

A few researchers examined the utilization of Jojoba oil as an alternative engine fuel. They emphasized the suitability of such promising fuel for diesel engines [12–14]. However, as reported by many researchers [15,16], the usage of Jojoba oil in the diesel engine decrease the engine thermal efficiency, increase the specific fuel consumption and increase the engine emissions, especially the NO_x emissions. Shehata and Abdel Razek [15], Huzayyin et al. [16], Saleh [17] and Al-Widyan et al. [18] investigated the performance and emissions of the diesel engine fueled by sunflower (S100) and blend of 20% Jojoba oil plus 80% pure diesel fuel (B20). The results showed that the brake thermal efficiency was reduced due to the lower heating value of S100 and B20 compared to diesel fuel. Also, they found that the CO and NO_x emissions were increased for both S100 and B20 compared to pure diesel fuel.

Currently, there is considerable attention to utilizing nanoparticles-additives to improve the combustion quality of the burned fuel. Metallic based and oxygen-containing compounds, such as Aluminum oxide (Al_2O_3), Titanium oxide (TiO_2), Copper oxide (CuO), and others which act as a combustion catalyst for hydrocarbon fuels [19], [20]. These additives enhanced the radiative mass transfer properties, reduced ignition delay and improved the ignition temperature parameters of the fuel within the combustion zone [21]. For engine applications, there are many trials to study the effect of nano-additives on engine performance. Accordingly, some experimental investigations were conducted with the use of nano-additives blends with biodiesel and diesel fuel to improve the fuel properties and engine performance, as well as to reduce the engine emissions [22–24].

Ganesh and Gowrishankar [25] studied the effects of the addition of Magnalium and Cobalt Oxide nanoparticles on diesel engine performance fueled by Jatropha biodiesel. They found that the addition of nanoparticles resulted in a significant improvement in the brake thermal efficiency and reduction in the bsfc by 2%. Also, the emissions have remarkable reduction where UHC was reduced by 60%, CO by 50% and the NO_x by 45%. Moreover, Solero [26] examined the effects of adding Al_2O_3 nanoparticles on the combustion characteristics of diesel fuel spray. He found that the addition of Al_2O_3 with a concentration of 0.1% by volume to diesel fuel improved the combustion characteristics of the fuel spray, and reduced the level of CO emission. In addition, Gürü et al. [27] studied the improvement of diesel fuel properties utilizing additives of organic compounds of Mn, Mg, Cu and Ca with different concentrations of 13.5, 27.1, 54.2, and 94.9 µmol/l blended fuel. The results showed that the Mn had the significant reduction in the fuel freezing point, while the cetane number was increased by about 5%. The CO emission was decreased by 14.3%, and the brake thermal efficiency was increased by 0.8%.

Furthermore, Selvan et al. [28], Sajeevan and Sajith [29] and Sajith et al. [30] investigated the impacts of Cerium oxide additives in diesel and diesel-biodiesel-ethanol blends on the diesel engines performance. They found that the addition of nanoparticles into diesel-biodiesel-ethanol blends decreased the specific fuel consumption, increased the peak pressure and shortened the ignition delay. The addition of Cerium oxide also accelerated earlier initiation of combustion and caused a lower heat release rate. Emissions of CO, UHC, and NO_x were significantly reduced. They also reported that the optimum engine performance was achieved at nanoparticles dose level of 35 ppm.

Kao et al. [31], Aalam and Saravanan [32] and Basha and Anand [33–35] also examined the effects of adding Aluminium (Al) nanoparticles and Aluminium oxide (Al_2O_3) with diesel, biodiesel, emulsified diesel fuel, and emulsified biodiesel fuel on a diesel engine performance. They found that the peak pressure, pressure rise rate, heat release rate, and the brake specific fuel consumption were reduced. The NO_x, CO, UHC, and soot emissions were remarkably reduced due to the addition of nanoparticles.

In another experimental investigation, Tyagi et al. [36] studied the effects of the addition Aluminium (Al) and Al_2O_3 nanoparticles on the ignition characteristics of diesel fuel. They found that the radiative and heat/mass transfer properties of diesel fuel were enhanced remarkably. They also reported that the hot plate ignition probability of the diesel fuel increased significantly. Also, Gan and Qiao [37] studied the impacts of the addition of nano and micron-sized Aluminum (Al) particles on combustion characteristics of n-decane and ethanol droplets by varying its size, dispersant concentration, and type of base fluid. They found that the engine power was remarkably enhanced. They also reported that the CO_2 and NO_x emissions were significantly reduced.

Mehta et al. [38] studied the engine performance and emission characteristics of a diesel engine operated with diesel fuel with the addition of Aluminum and Iron nanoparticles. They found that the peak cylinder pressures and the brake thermal efficiency were increased by 4% and 9%, respectively while the bsfc was decreased by 7%. Engine emissions of CO and UHC were reduced by 40%, and 8% respectively. Kannan et al. [39] examined the effects of ferric chloride ($FeCl_3$)