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Performance, combustion, and emission characteristics of a diesel engine fueled with Jatropha methyl ester and graphene oxide additives

Ahmed I. EL-Seesy[a,d,*], Hamdy Hassan[a,b], S. Ookawara[c]

[a] Department of Energy Resources Engineering, Egypt-Japan University of Science and Technology (E-JUST), 21934 Alexandria, Egypt
[b] Department of Mechanical Engineering, Faculty of Engineering, Assiut University, Assiut 271516, Egypt
[c] Department of Chemical Science and Engineering, School of Materials and Chemical Technology, Tokyo Institute of Technology, Tokyo, Japan
[d] Department of Mechanical Engineering, Benha Faculty of Engineering, Benha University, 13512 Benha, Qalubia, Egypt

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ABSTRACT

The present experimental study aims at investigating the impact of adding graphene oxide nanoparticles (GO) to neat Jatropha Methyl Ester (JME) on a single cylinder air cooled direct injection four stroke diesel engine. The nano-fuels have been prepared from 25, 50, 75 and 100 mg/l concentrations of graphene oxide with neat Jatropha biodiesel through ultrasonication process. The graphene oxide nanoparticles crystallite size, morphology, and the chemical structures were examined using X-ray diffraction (XRD), Transmission Electron Microscope (TEM), and Fourier-transform infrared spectroscopy (FTIR), respectively. The compression ignition engine characteristics were investigated by the four JME-GO blends, and their results were compared with neat JME under various engine loads at a constant engine speed of 2000 rpm. The results indicate that the diesel engine operated by JME-GO nano-fuels enhanced the brake thermal efficiency by 17% compared to neat JME fuel. Furthermore, the peak cylinder pressure, the highest rate of pressure rise, and maximum heat release rate were also increased by 8%, 6%, and 6%, respectively. The CO and UHC emissions were decreased significantly by 60% and 50%, respectively, for JME-GO blends compared to pure JME fuel. At high engine load, the NO_x emission was reduced by 15% for JME-GO blends compared to pure Jatropha biodiesel. The results also illustrated that the concentration of 50 mg/L had the optimum improvement in the overall characteristics of engine performance and emissions.

1. Introduction

Growing energy desires, depletion of fossil fuels and rigorous emission standard forced the scientific society to search for alternative fuels such as biodiesel for diesel engine applications in order to decrease the gap between demand and energy source for automotive sector [1]. Biodiesels are readily available, bio-degradable, portable, nontoxic and renewable source. It can be produced from a variety of natural feedstock sources and globally around 350 crops are accepted as the potential feedstock for biodiesel production [2]. There are different sorts of seeds from the plants like pongamia, jatropha, mahua, castor, and jojoba are employed to produce biodiesel where they are recommended by most of the scientific researchers. These non-edible oil plants are recognized as second generation feedstock due to their economically cheap and easily cultivated in many parts of the world [3]. However, the viscosity of the raw vegetable oils is considered the main problem which hinders to use it directly in diesel engines. Therefore, to tackle this issue, transesterification process is a widely used technique to reduce vegetable oil viscosity which considers the most feasible and viable approach. By using this technique, all non-edible oil can be brought down to similar diesel characteristics. Jatropha seeds are one of the promising non-edible feedstock for biodiesel production due to its long-life capability in nature for about 50 years. It is available in many places such as Asia, South Pacific, and East Africa, etc. [4]. Consequently, jatropha oil and its derivatives have a great potential to be utilized in biodiesel production and in many other applications [3,4].

There are numbers of research studies that were examined on diesel engines with Jatropha biodiesel as fuel under different operating conditions. Although it is considered as a promising alternative source for diesel engines, it still has an adverse effect on exhaust emissions, particularly NO_x emission [3]. In recent decades, there are several studies have focused on nanoparticle additives to biodiesel fuels because these additives have considerable impacts on the combustion characteristics of biodiesel fuels [5,6]. The influence of adding nanoparticle additives

* Corresponding author at: Department of Energy Resources Engineering, Egypt-Japan University of Science and Technology (E-JUST), 21934 Alexandria, Egypt.
E-mail addresses: ahmed.elsisi@ejust.edu.eg, ahmed.elsysy@bhit.bu.edu.eg (A.I. EL-Seesy).
URLS: https://ejust.edu.eg/, http://beng.bu.edu.eg/beng/en/ (A.I. EL-Seesy).

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Nomenclature

A	surface area, m^2
$A(\theta)$	instantaneous combustion chamber surface area, m^2
A_{ch}	cylinder head surface area, m^2
A_{PC}	piston crown surface area, m^2
ASTM	American Society for Testing and Materials
ATDC	after top dead center
B	cylinder bore diameter, m
CA	crank angle, degree
CO	carbon monoxide, ppm
EGT	exhaust gas temperature, °C
EVC	exhaust valve closed
EVO	exhaust valve opened
GO	graphene oxide
h_c	heat transfer coefficient, W/(m^2·K)
IVC	inlet valve closed
JME	Jatropha methyl ester
JME25GO	JME + 25 mg/L of graphene oxide
JME50GO	JME + 50 mg/L of graphene oxide
JME75GO	JME + 75 mg/L of graphene oxide
JME100GO	JME + 100 mg/L of graphene oxide
L	engine stroke, m
N	engine speed, rpm
NO_x	nitrogen oxides, ppm
p	instantaneous in-cylinder pressure, bar
T	mean gas temperature, K
T_w	wall temperature, K
U	internal energy, kJ/kg
UHC	unburned hydrocarbons,%
V	instantaneous cylinder volume, m^3
V_c	clearance volume, m^3
V_d	displacement volume, m^3
V_m	mean piston speed, m/s
W	work, kJ/kg
$dp/d\theta$	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

Greek symbols

θ	crank angle, deg
τ_{max}	ratio of θ_{max} to θ_d

with diesel, biodiesel and diesel-biodiesel blends on a diesel engine performance and emission parameters was comprehensively surveyed by Saxena et al. [5] and Khalife et al. [6]. They concluded that the metallic-based additives and multiwalled carbon nanotubes additive have been demonstrated promising in terms of their impacts on engine performance and emission characteristics. Their positive attributes have been related with reducing ignition delay and the highly reactive surfaces of multiwalled carbon nanotubes resulting in a cleaner combustion. These additives act as a catalyst in the combustion zone, resulting in a significant reduction in emissions [7]. Such additives were also found to improve the heat transfer between the fuel and air, which shorted ignition delay and promoted the combustion process [8,9]. There are several experimental studies that were investigated the impact of adding nanoparticles into biodiesel and diesel fuels which will be presented as follow.

Nanthagopal et al. [10] investigated the effects of adding zinc oxide and titanium dioxide nanoparticles to biodiesel blends on a diesel engine performance and emission characteristics. The results showed that the thermal efficiency was improved by approximately 17% whereas the engine emissions of NO_x, CO, UHC, and soot were decreased significantly by 29%, 40%, 40%, and 30%, respectively. Furthermore, Nanthagopal et al. [11] analyzed the impacts of adding zinc oxide nanoparticles and Ethanox, which is an antioxidant, into biodiesel fuel on a diesel engine performance and emission characteristics. The results illustrated that the thermal efficiency was enhanced by approximately 25% whereas the NO_x emission was decreased by approximately 18%. However, the CO and UHC emissions were increased by approximately 20% and 15%, respectively.

Moreover, the effects of adding ceria and aluminum oxide nanoparticles to emulsified biofuel blends and biodiesel-diesel blends on the engine performance and emissions were studied by EL-Seesy et al. [12], Khalife et al. [13], Muthusamy et al. [14] and Annamalai et al. [15]. They found that the UHC, NO_x, CO, and smoke emissions were reduced by 35%, 25%, 26% and 20%, respectively. Additionally, the thermal efficiency was increased by 17%, whereas the brake specific fuel consumption (bsfc) was reduced by 15%. Also, the cylinder peak pressure and heat release rate were slightly reduced. Moreover, the influences of adding cerium oxide nanoparticles (CERIA) and CNTs into diesterol (diesel, biodiesel, and ethanol) fuel blends and biodiesel-diesel blends on a diesel engine performance was examined by Selvan et al. [16], Mirzajanzadeh et al. [17], and Maleney et al. [18]. The results illustrated that the brake thermal efficiency and the maximum pressure were enhanced by approximately 15% and 5%, respectively. Engine emissions of UHC, CO, and smoke were reduced by 30%, 50%, and 25%, respectively, while the NO_x emission was increased by approximately 12% due to the CNTs additives.

Furthermore, the impacts of adding CNTs and silver nanoparticles to diesel–biodiesel blends on a diesel engine performance were investigated by Najafi [19], Hosseini et al. [20], EL-Seesy et al. [21,22], and Ghanbari et al. [23]. The results showed that the power and thermal efficiency were enhanced by approximately 4% and 8%, respectively. In addition, the engine emissions of CO, UHC, and soot were decreased significantly by approximately 65%, 45%, and 30%, respectively whereas the NO_x emission was increased by approximately 27%. Recently, Hoseini et al. [24] and EL-Seesy et al. [25] examined the influence of adding nanographene oxide and graphene nanoplatelet with diesel-biodiesel blends on a diesel engine performance and emission parameters. The combustion results showed that the peak pressure, highest rate of pressure rise, and maximum heat release rate were enhanced by 6%, 5%, and 5%, respectively. They revealed that the brake power was improved by about 16% while the bsfc was reduced by approximately 15%. Engine emissions of CO and UHC were decreased by 18% and 28%, respectively, whereas the NO_x emission was increased by 8%.

In recent decades, there have been remarkable efforts concentrating on the use of different metal oxide-based nanoparticle additives such as zinc oxide, titanium dioxide, aluminum oxide, and cerium oxide to enhance the combustion manner of diesel and biodiesel and to decrease diesel engine emissions [5,6,10]. Although the advantages reported earlier, metal nanoparticle additives and metal compounds generated from combustion byproducts have been found to be toxic and harmful to the environment [26]. For instance, there are several studies have illustrated that metal oxide nanoparticles can cause various sorts of health issues such as breathing issues, lung-related problems, and skin allergies [26]. However, graphene oxide (GO) can be an environmentally friendly fuel additive for improving the combustion process of diesel–biodiesel blended fuels efficiently owing to its low toxicity, high energy density, and high thermal conductivity [24,27,28]. The beneficial properties of GO and related carbon nanomaterials have been confirmed in several applications such as in batteries, chemical sensors, heat transfer, and transparent conductors [29,30]. The ultra-thin and layered nanostructure of GO and the