Energy 147 (2018) 1129–1152

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Effects of graphene nanoplatelet addition to jatropha Biodiesel–Diesel mixture on the performance and emission characteristics of a diesel engine

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ARTICLE INFO

Article history:
Received 2 May 2017
Received in revised form
26 November 2017
Accepted 22 January 2018

Keywords:
Jatropha methyl ester
Graphene nanoplatelets
Diesel engine
Heat release rate
Engine performance
Emission characteristics

ABSTRACT

In this study, the effects of adding graphene nanoplatelets (GNPs) into jatropha methyl ester–diesel blended fuel (20% by volume jatropha methyl ester + 80% diesel; symbolized by JB20) on the performance, combustion, and emission characteristics of a diesel engine were experimentally investigated. The GNPs were added at different concentrations of 25, 50, 75, and 100 mg/L of JB20. These blends were investigated under various engine loads and speeds. The results showed that adding GNPs at 50–75 mg/L of JB20 achieved an increase of 25% in the thermal efficiency and a reduction of 20% in the brake specific fuel consumption compared to those of pure JB20. The peak cylinder pressure, highest rate of pressure rise, and maximum heat release rate were also increased by 6%, 5%, and 5%, respectively. Furthermore, the engine emissions of NO_x, CO, and UHC were reduced by 40%, 60%, and 50%, respectively, at a GNP dosage of 25–50 mg/L. The results showed that the dose level of 50 mg/L had the optimum enhancement in the overall characteristics of engine performance and emissions.

1. Introduction

The effective conversion and availability of energy are the main problems affecting the socio-economic situation in any country [1–3]. One of the primary energy conversion devices is the compression ignition engine or diesel engine, which is preferable in its category owing to some advantageous features. Diesel engines have low specific fuel consumption and high thermal efficiency owing to their high compression ratio, low pumping work, and lean fuel–air operating conditions. In addition, they have high reliability and low operating and maintenance cost, enhancing their benefits in different sectors such as electricity generation, automobile sector, and agricultural machinery [2,4]. However, compression ignition engines emit large quantity of emissions (NO_x, soot, CO, UHC, and particulate matter) causing serious health hazards and environmental degradation [4–6]. Additionally, petroleum-derived fuels are declining and are predicted to provide our energy requirements until the middle of the 21st century because of the significant increase in energy demand and population [7]. There are several techniques to reduce diesel exhaust emissions. These include engine design modification, combustion enhancement, and use of treatment devices for exhaust systems [5,8]. The enhancement of engine combustion is the most recommended approach because it requires only few modifications of engine systems compared to the use of new designs or additional systems. This technique is achieved by adjusting the fuel properties, enhancing fuel injection, and using fuel additives. One approach is by utilizing biodiesel as an oxygenated fuel, which is a promising alternative to the conventional diesel fuel [2,4]. Biodiesel is gaining more acceptance as a promising alternative energy resource because of the global fossil fuel shortage and emission issues [9,10]. It is considered as an excellent choice for diesel engines because it is biodegradable, oxygenated, non-toxic, and environmentally friendly [5]. However, using biodiesel has raised both the market price of edible oils and biodiesel, leading to food security problems.

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https://doi.org/10.1016/j.energy.2018.01.108
0360-5442/

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
D100	Neat diesel oil
EGT	Exhaust gas temperature, °C
EVC	Exhaust valve closed
EVO	Exhaust valve opened
h_c	Heat transfer coefficient, $W/(m^2 \cdot K)$
IVC	Inlet valve closed
JB20	Fuel mixture containing 20% JAME + 80% D100
JAME	Jatropha methyl ester
$JB20_{25GNPs}$	JB20 + 25 mg/L of graphene nanoplatelets
$JB20_{50GNPs}$	JB20 + 50 mg/L of graphene nanoplatelets
$JB20_{75GNPs}$	JB20 + 75 mg/L of graphene nanoplatelets
$JB20_{100GNPs}$	JB20 + 100 mg/L of graphene nanoplatelets
L	Engine stroke, m
GNPs	Graphene nanoplatelets
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

Therefore, to overcome the issues on food requirements worldwide, the biomass resources should be non-edible [8]. The most recommended non-edible oils are those produced from plants that do not require large amounts of water or can be cultivated in arid lands by the use of wastewater [8].

Jatropha curcas is one of the energy crops that has high potential as an energy resource. It can be cultivated in many types of soils such as barren land or wasteland, which helps to reduce the competition with edible oil plants [11]. Fruit production can begin from the second year of planting but in a limited amount. However, starting from the 5th year onward, a tree can produce 4–5 kg of fruits if cultivated properly, and it can continue to be productive up to 40–50 years from the day of cultivation [12]. The most recent studies have used different techniques to extract jatropha oil from its seeds [13]. Those techniques were mostly mechanical pressing, mechanical pressing followed by solvent extraction, or solvent extraction only. It was found that the quality of jatropha oil is similar to that of rapeseed oil as a fuel [14]. Jatropha oil contains more than 75% unsaturated fatty acid, which affects its physical and chemical properties [14]. The jatropha seeds contain approximately 30% oil that can produce biodiesel with high quality through the transesterification process [14]. Consequently, jatropha oil and its derivatives have a great potential to be used in biodiesel production and in many other applications [11,14].

Several studies have examined the performance and emission characteristics of diesel engines fueled by biodiesel–n-butanol, biodiesel–ethanol, and biodiesel–2,5-dimethylfuran (DMF) [15–17]. The results showed that the thermal efficiency was improved, and the smoke was reduced significantly because of the additives to biodiesel fuel. Meanwhile, UHC and CO emissions were increased at low engine loads but they were reduced significantly at high loads. However, the NO_x emission was increased when the engine was operated by neat biodiesel, B20, and DMF20.

In recent years, several studies have concentrated on nanoparticle additives to biodiesel fuels because these additives have significant effects on the combustion parameters of biodiesel fuels [18–21]. This effect is attributed to the high surface area to volume ratio and high thermal conductivity of the nanoparticles. These additives act as a catalyst in the combustion zone, leading to a considerable reduction in emissions [22]. Such additives were also found to enhance the heat transfer between the fuel and air, which decreased ignition delay and improved the combustion process [23,24]. In the next paragraphs, a review of several experimental studies is presented on nanoparticle additives into biodiesel and diesel fuels to improve the fuel properties and engine performance and reduce the engine exhaust emissions.

Nanthagopal et al. [25] examined the performance and emission characteristics of a diesel engine fueled by biodiesel blended with zinc oxide and titanium dioxide nanoparticles. They found that the thermal efficiency was increased by approximately 17% while the engine emissions of NO_x, CO, UHC, and soot were reduced by 29%, 40%, 40%, and 30%, respectively. In addition, Nanthagopal et al. [26] examined the effects of adding zinc oxide nanoparticles and Ethanox, which is an antioxidant, into biodiesel fuel on diesel engine performance and emission characteristics. They found that the thermal efficiency was increased by approximately 25% while the NO_x emission was reduced by approximately 18%. However, the CO and UHC emissions were increased by approximately 20% and 15%, respectively.

Furthermore, Khalife et al. [27] investigated the effects of adding cerium oxide nanoparticles to emulsified diesel–biodiesel on diesel engine performance and emissions. They found that the thermal efficiency was increased by 23%, whereas the brake specific fuel consumption (bsfc) was reduced by 16%. Additionally, the CO, UHC, and NO_x emissions were reduced by 51%, 45%, and 27%, respectively. Jena et al. [28] studied the performance and emission characteristics of a diesel engine fueled by diesel fuel with the addition of ferric chloride. They found that the brake thermal efficiency was increased by 2.7%, whereas the bsfc was reduced by 8.3%. The CO, UHC, and soot emissions were reduced by 45%, 47%, and 64%, respectively. However, the NO_x emission was increased by 15%.

In addition, Muthusamy et al. [29] examined the performance and emission characteristics of a diesel engine fueled by diesel–biodiesel fuel added with aluminum oxide nanoparticles. They found that the brake thermal efficiency was increased by approximately 30% while the bsfc was decreased by approximately