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Performance, combustion, and emission characteristics of a diesel engine fueled by biodiesel-diesel mixtures with multi-walled carbon nanotubes additives

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ABSTRACT

In this work, the effects of adding Multi-Walled Carbon nanotubes (MWCNTs) to Jojoba methyl ester-diesel blended fuel (JB20D) on performance, combustion and emissions characteristics of a compression-ignition engine were experimentally investigated. The JB20D with 10, 20, 30, 40 and 50 mg/l of MWCNTs were examined at different engine loads and speeds. Compared to pure diesel, the use of JB20D without MWCNTs caused a slight decrease in the engine performance and an increase in the engine emissions at most examined conditions. 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 at the dose level of 50 mg/l compared to JB20D. The MWCNTs-JB20D blended fuel also brought about an enhancement in combustion characteristics where the peak cylinder pressure, the maximum rate of pressure rise and the peak heat release rate were increased by 7%, 4%, and 4%, respectively, at the same dose level. According to the measured emissions, a significant reduction of engine emissions was achieved at the dose level of 20 mg/l, where NO_x, CO, and UHC were reduced by 35%, 50%, and 60%, respectively. According to the obtained results, the recommended concentration of MWCNTs in JB20D was concluded to be 40 mg/l, which could give significant improvements in overall the parameters of engine performance and emissions with a good balance between them.

1. Introduction

Diesel engines have been widely used in power generation sector, heavy machinery and public transportation due to their high reliability, durability, and high fuel efficiency. There are two main challenges to hold their positioning as one of the most common power generators. The first is related to the limited crude oil resource on land. The second is concerned with the environmental pollution. It is hard to minimize the emission of nitrogen oxide (NO_x) and smoke simultaneously in diesel engines, due to the trade-off relationship between them. Therefore, the control of both NO_x and smoke emissions are still the major dilemma in the development of diesel engines [1,2]. There are major approaches to reduce diesel emissions; including engine design modifications, combustion enhancement, and the use of treatment tools for exhaust gases [3]. The improvement of engine combustion appears to be the most recommended technique; essentially because it may require only small modifications of engine systems rather than the use of new designs or the use of additional systems. This approach is realized by regulating the fuel properties, improving fuel injection, and/or adding fuel additives. In this regard, the use of biodiesel as an oxygenated fuel was found to be a promising alternative to the conventional diesel fuel [4]. The biodiesel fuels have significant benefits in terms of emission and resource. The utilization of biodiesel fuels can reduce the amount of diesel consumed, and smoke or particulate matter without major modification of the engine. Consequently, such fuels have wide applicability to future vehicles as well as those in the present use [3], where most biodiesel fuels exist in liquid form at ambient

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Nomenclature

A	surface area, m^2
A(θ)	the instantaneous combustion chamber surfaces 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, deg.
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, $W/m^2{\cdot}K$
IVC	inlet valve closed
JME	Jojoba Methyl Ester
JB20D	mixture fuel containing 20% JME + 80% D100
JB20D10MWCNTs	mixture fuel (JB20D) + 10 mg of multi-walled carbon nanotubes
JB20D20MWCNTs	mixture fuel (JB20D) + 20 mg of multi-walled carbon nanotubes
JB20D30MWCNTs	mixture fuel (JB20D) + 30 mg of multi-walled carbon nanotubes
JB20D40MWCNTs	mixture fuel (JB20D) + 40 mg of multi-walled carbon nanotubes
JB20D50MWCNTs	mixture fuel (JB20D) + 50 mg of multi-walled carbon nanotubes
L	engine stroke, m
MWCNTs	multi-walled carbon nanotubes
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/dθ	presser rise rate per crank angle, bar/deg.
dV/dθ	volume rise rate per crank angle, m^3/deg.
$dQ_g/d\theta$	gross heat release rise rate per crank angle, J/deg.
θ	crank angle, deg.

temperature, and hence, it can be readily stockpiled and transported. The most significant problem associated with biodiesel fuels is the use of edible oil as feedstocks for biodiesel production. This problem may be represented in the competition with the edible oil market, which raises both the cost of edible oils and biodiesel. Therefore, to completely overcome the problems related to food requirements all over the world, the biomass resources should be non-edible [3]. The most recommended non-edible oils are those generated from plants that do not need a huge amount of water or can grow in the barren lands using wastewater [5].

Jojoba is a name that is becoming common as an industrial crop in some countries. At present, growers are producing this obscure desert shrub in USA, Latin America, South Africa and many other countries. In addition, it can be grown in waste lands that are not proper for food crops, and the cost of agriculture is extremely lower because these crops can still sustain reasonably high yield without intensive care [2]. Also, the standard Jojoba water requirement per Feddan is about 1600 m^3/year [6]. This means that Jojoba shrub can be categorized as a low water requirement plant. The first endeavors to grow Jojoba in Egypt were initiated in 1976 with no success. In 1985, Food and Agriculture Organization adopted five years research and development program to introduce Jojoba in Egypt and other Middle East Countries, as a new crop including adoption principles stages of appropriate new crop adoption [6]. The results were not up to expectations owing to the failure of generating high yield shrubs by vegetative propagation as well as the shortage of agriculture technique know-how. However, a new major project was started in 1990 to cultivate Jojoba and open new markets for its products. In May 1991, nine Feddans were planted by seeds and expansions are still continuing in the cultivation of the jojoba plant [6]. Consequently, in recent years Jojoba oil has become the most genuinely Egyptian product [7]. From the literature, most of the studies used various methods for extraction of Jojoba oil from the seeds [8]. Those techniques are mainly mechanical pressing, mechanical pressing followed by solvent extraction, or solvent extraction only. Jojoba oil is mainly composed of straight-chain wax esters in the range of C26–C48 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 [8]. Accordingly, Jojoba oil and its derivatives have a great potential for use in cosmetics, pharmaceuticals, lubricants, and many other applications [7]. The seed of Jojoba contains raw oil with the weight ratio more than 50%, and hence, pure Jojoba oil is a suitable feedstock for biodiesel production. Furthermore, the choice of the Jojoba oil as a biodiesel fuel is due to its availability in many countries, its low price, and its low chemical reactivity [6,8]. The raw Jojoba oil is converted into Jojoba Methyl Ester (JME) via transesterification process. It has many advantages as it performs under normal conditions and yields better quality biodiesel. The biodiesel production via transesterification depends upon many parameters, the most important of which are type and amount of alcohol, type and the amount of catalyst, the reaction time, and reaction temperature.

Few studies have examined the utilization of Jojoba oil as an alternative engine fuel. Radwan et al. [10], Selim et al. [11] and Selim et al. [12] confirmed the appropriateness of such promising fuel for diesel engines. However, as reported by many researchers [12–15], the utilization of Jojoba oil in diesel engines decreases the engine brake thermal efficiency, increases the specific fuel consumption and the engine emissions, especially NO_x emissions. Huzayyin et al. [13] studied the effect of Jojoba oil-diesel blended fuel on the performance and exhaust emissions of the diesel engine. They used different blends of Jojoba-diesel fuel with variable engine speeds and loads. They found that the engine power output and brake mean effective pressure were reduced with the addition of Jojoba oil to pure diesel fuel. Also, the brake specific fuel consumption (bsfc) was increased with increasing the Jojoba-diesel blending ratio. The reason was the decrease in the calorific value of the fuel blend with the rise of jojoba oil proportion in the mixture. They reported that the NO_x and CO emission were slightly increased with increase in the Jojoba-diesel blend ratio.