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The Influence of Multi-Walled Carbon Nanotubes Additives into Non-Edible Biodiesel-Diesel Fuel Blend on Diesel Engine Performance and Emissions

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Abstract

This paper reports on an experimental investigation that was conducted to recommend the most suitable dose level of multi-walled carbon nanotubes (MWCNT) into biodiesel-diesel fuel blend at which the optimum diesel engine performance is attained. In this study, nano-particles of size from 10 to 15 nm with tube length 1-10 microns, the dose level is varied from 10 to 50 mg/l by step of 10 mg/l was mixed into the biodiesel-diesel fuel blend with the help of ultrasonicator. A single cylinder diesel engine test facility was used to study the effect of nanoparticles dose level on engine combustion and environmental performance parameters with a constant speed of 2000 RPM and different engine torque. The results of the present study showed that the biodiesel-diesel fuel blend slightly decreases the mechanical engine performance and increases its emission characteristics at all tested engine operating conditions. The use of MWCNTs is found to improve all engine performance parameters no matter the studied dose level. However, the best emission characteristics are obtained at a dose level of 30 mg/l (where remarkable emission reduction is observed; NO_x by 45 %, CO by 50 %, and UHC by 60 %). While the best of engine combustion characteristics are achieved at a dose level of 50 mg/l (the increase in the in-cylinder peak pressure - $P_{max,}$ is about 7 %). Finally, it valuable to recommend the dose level of 40 mg/l where reasonable improvement in engine performance is achieved.

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Keywords: Jojoba Methyl Ester; Multi-walled Carbon Nanotubes; Diesel Engine; Engine Performance; Emission Characteristics.

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1. Introduction

The diesel engines are the major engine type for heavy duty applications in transportation and power generation sectors. Nevertheless, diesel engines are considered one of the primary sources of many toxic emissions, in particular, 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. There are major approaches to reduce diesel emissions; including the engine design modifications, the engine combustion enhancement, and the use of exhaust gas treatment technique [1, 2]. The modification of engine combustion seems to be the most recommended given it may need only minor modifications 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/or use of fuel additives [2]. In this regard, the use of oxygenated fuels as biodiesel is found to be a promising alternative substitute for the conventional diesel fuel. Jojoba plant is one of the promising non-edible plants growing in desert lands, and its seed has more than 50% of its weight as raw oil [3] and [4]. So raw jojoba oil would be a suitable feedstock for biodiesel production. The raw jojoba oil is converted into biodiesel via transesterification process to obtain Jojoba Methyl Ester (JME). A few researchers have investigated the utilization of Jojoba oil as an alternative engine fuel. Radwan et al.[4], Selim et al.[5], and Al-widyan & Al-muhtaseb [6] emphasized the suitability of such promising fuel for diesel engines. However, as reported by many researchers, the use of Jojoba oil in the diesel engine decreases the engine thermal efficiency, increases the specific fuel consumption and increases the engine emissions especially the NO_x emissions [7] and [8].

Recently, there is a considerable attention to using nanoparticle additives to enhance the combustion quality of the burned fuel. Using the nanoparticles in the form of oxides as aluminum oxide, cerium oxide, and others in the combustion zone act as a catalyst [9]. These additives enhanced the radiative-mass transfer properties, reduce ignition delay and enhance the ignition temperature characteristics of the fuel within the combustion zone [10]. For engine applications, there are many investigations to study the effect of nanoparticle additives on engine performance. Correspondingly, a number of 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 [9 -12].

Prajwal et al. [12], studied the performance of a single cylinder diesel engine using multiwall carbon nanotube blended biodiesel fuels. It was found that the brake thermal efficiency for biodiesel-multi walled carbon nanotubes blended fuel were relatively better as compared to that of biodiesel only. This could probably be attributed to the better combustion characteristics of multi-walled carbon nanotubes, due to high surface area and reactive surfaces that contribute to higher chemical reactivity to act as a potential catalyst. Also, the CO, HC, and smoke emissions were lower for biodiesel multi-walled carbon nanotubes blended fuel as compared to that pure biodiesel fuel. This could be due to catalytic activity and improved combustion characteristics of multi-walled carbon nanotubes, which leads to improved combustion characteristics. Furthermore, the NOx emission was relatively less for biodiesel-multi-walled carbon nanotubes blended fuel as compared to that of the diesel oil. This is because of reduced ignition delay that resulted in higher premixed combustion fraction and higher peak temperatures.

According to the previous researches and ASTM standard, the most recommended blending ratio of the biodiesel is B20 [8]. Therefore, the current study will be performed based on this blending ratio with different nano-additives dose levels. Therefore, the present work objectives to investigate the effect of the nano-additives on the performance of a diesel engine fuelled by JME-diesel blended fuel.

2. Nomenclature

ASTM:	American Society for Testing and Materials	JB20D20MWCNT:	JB20D+ 20 mg MWCNT
CA:	Crank angle, degree	JB20D30MWCNT:	JB20D+30 mg of MWCNT
CO:	Carbon monoxide, ppm	JB20D40MWCNT:	JB20D+40 mg of MWCNT
D100:	Neat diesel oil	JB20D50MWCNT:	JB20D+50 mg of MWCNT
EGT:	Exhaust gas temperature, °C	MWCNT:	Multi-walled Carbon Nanotubes
JME:	Jojoba methyl ester	UHC:	Unburned hydrocarbons, %Vol.

JB20D:	20% JME + 80% D100	NOx:	Nitrogen oxides, ppm
JB20D10MWCNT:	JB20D+10 mg of MWCNT		

3. Experimental Setup and Procedure

GUNT experimental test rig (model CT100.22) with a single cylinder direct injection diesel engine (model HATZ-1B30-2) of the technical specifications summarized in Table 1 was employed as the test engine in the present work. The whole experimental layout equipped with the necessary instruments to measure the different engine parameters is shown in Figure 1. Asynchronous motor (model TFCP 132SB-2) of the maximum electric power output of 7.5 kW power fitted directly to the test engine and mounted in floating bearings to measure the engine brake torque, also acts as a starter motor. The brake torque is measured by using force sensor (FLINTEC model ZLB-200Kg-C3). The output power of the asynchronous motor is consumed in return power unit existing in the CT100.22 control unit. The test rig provides a facility to measure the engine performance at different operating conditions of engine load and engine speed. The torque values are chosen and defined by selecting switch on the control unit (CT 100.22), which is displayed on a digital scale. The engine brake power has been calculated by measuring both of brake torque and engine speed simultaneously. The speed is measured using the proximity sensor (WACHENDORFF proximity sensor, type PNP-N.O, Sn 4mm,10-30VDC, and 200 mA) which is fitted to the coupling on device breaking, which is represented on a digital display.

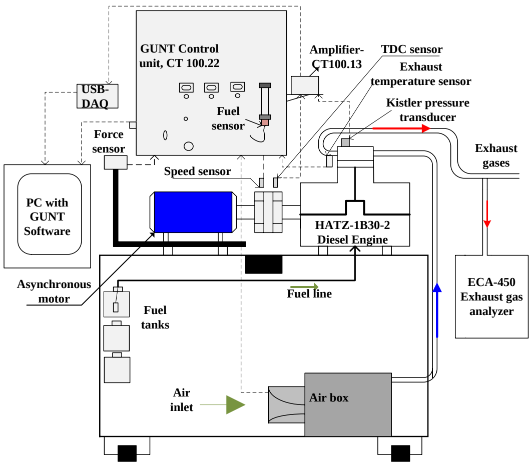

Fig.1: Schematic diagram of the test rig

Table 1: Technical specifications of the diesel engine

Engine parameters	Specification
Engine model	HATZ-1B30-2
Bore/ Stroke, mm	80/69
Rod length, mm	114.5
Displacement, cm^3	347
Compression ratio	21.5:1
Rated power, kW	5.4 at 3600 RPM
Idle Speed, RPM	1000
Type of Injection.	Direct injection
Type of cooling.	Air cooling

The fuel mass flow rate can be measured in two-ways, the first is through recording the time required to consume a specific volume of the fuel contained in a glass tube with a scale in centimeters (measurement of fuel consumption is based on the following relation: one cm = 4.8 cm^3 fuel). The second, through using flow meter sensor (Huba control type 680- out signal 0-10 VDC) which is fitted with the glass tube at the bottom. The intake airflow rate is measured by the orifice meter, which is fitted in the air box. The inlet and outlet of the orifice are connected to a differential pressure manometer. The measured differential pressure is displayed in Pa or as speed in m/s (with a scale from 0 to 28 m/s) and then converted to a volumetric flow rate (with a range from 0 to 560 l/min) using the known measuring orifice diameter of 20.6 mm. The ambient air temperature, exhaust gasses temperature, and fuel temperature are measured using a thermocouple. For this purpose, three calibrated thermocouple probes of type (K) are installed in these locations. The output of the thermocouples is displayed on a digital scale in °C. All the signal output from the force sensor, temperature thermocouples, fuel flow meter sensor, air flow meter sensor, and speed sensor are sent to DAQ existing in CT100.22 unit; then it is displayed on PC through LabView software (GUNT software).

The emission is measured by environmental combustion analyzer (BACHARACH model ECA- 450) a self-calibrated exhaust analyzer. A pump sucks the exhaust gasses to be analyzed and distributes to the different built-in electrochemical (for O_2, CO, UHC, and NO_x) sensing cells.

The cylinder pressure is measured by a Kistler piezoelectric pressure sensor (model 6052C of pressure range up to 250 bar and sensitivity ≈ -20 pc/bar) connected with charge amplifier (model GUNT CT100.13). The proximity switch of model Wachendorff PNP-N.O (for detecting the distance of 4 mm supplied with DC voltage 10-30VDC and 200mA) that is fitted with engine shaft at the location of piston top dead center (TDC). Both signals from charge amplifier and the proximity are converted from analog to digital data via Data-Acquisition Card (DAQ model USB-AD16f, 16 Analog Inputs, 250 kHz, 16 Bit, & ±10V) that is installed on PC and controlled by LabView software (GUNT software).

The evaluations of the uncertainty in the current measurements have been carried out following the procedure of Kline [13]. The uncertainty in the measurement of brake specific fuel consumption, brake power, and engine speed are found to be 2.3 %, 1 %, and 0.18 % (± 2 rpm), respectively.

The test steps discussed in the current work starts by warming up the engine for about 10 min using diesel fuel in the main tank. Next, the fuel line is switched to use the test fuel. Then, the specified engine load percentage is adjusted by regulating the torque value supplied to the force sensor on the asynchronous motor. After that, the rack arm is used to control the required engine speed. Finally, the different readings from the measuring devices for a particular test are recorded at steady state condition of the engine operation. This step is repeated to cover all the tested fuel (D100, JB20D, JB20D10MWCNT, JB20D20MWCNT, JB20D30MWCNT, JB20D40MWCNT and JB20D50MWCNT) at the specified load percentage. At the end of a test, the engine is allowed to run using diesel oil for about 10 min, under no load at 1000 RPM to avoid thermal cracking, and to make sure the fuel line system is cleaned from any residuals of the previously tested fuel.

4. Jojoba Biodiesel Production and Dispersion with MWCNT

The Egyptian raw Jojoba oil is used to produce the biodiesel fuel using a laboratory-scale setup. The test setup consists of a mechanical stirrer (servo-dyne mixer head with stirring speed up to 6000 RPM), three beakers (2000 ml, 500ml, and 250 ml), sensitive scale, controlled hot plate, and temperature thermocouple fitting into the flask to observe the reaction temperature.

The nanoparticles are dispersed into a mixture of Jojoba biodiesel-diesel fuel at the recommended composition (JB20D) with the aid of an ultrasonicator (Hielscher ultrasonic UP400S, 400 watts & 24 kHz) set at a frequency of 24 kHz for 30 minutes. The nanoparticles are dispersed into biodiesel mixture by using ultrasonication pulsating frequencies technique to avoid the nanoparticles agglomeration in the fuel blended [10]. The multi-walled carbon nanotubes (MWCNT) of mean outer diameter in the range of 10-15 nm (5-15 walls) with length ranging from 1-10 µm are supplied by Arkema Graphistrenght-C100 France Company. The nanoparticles are weighted according to the predefined mass fraction in the range of 10 to 50 mg/l with step 10 mg.

5. Results and Discussions

The combustion and emissions characteristics of a diesel engine using different fuels; including diesel and Jojoba biodiesel-diesel fuel containing 20% by vol. as JME (JB20D) with and without nanoparticle additives have been determined. Based on the combustion data, the cylinder pressure is plotted against crank angle. The emissions concentrations of NOx, CO, and UHC are plotted against the engine torque.

5.1 Combustion Characteristics

The change of in-cylinder pressure as a function of the crank angle during the end of the compression stroke and throughout the initial part of the expansion stroke is recorded for the studied fuels as shown in Figure 2. The use of the recommended JME-diesel fuel blend (JB20D) leads to a lower value of peak pressure (by about 6 %), and its location is retarded when compared with the behavior of diesel fuel. This can be attributed to the adverse effect of its higher viscosity and molecular weight which lead to ineffective utilization of fuel energy contents [4] and [5].

However, the retardation to receive this peak value can be attributed to the increase in the ignition delay period necessary to balance the effect of the high viscosity of fuel burned that worsen the processes of fuel atomization and evaporation. These results have a good agreement with Shehata and Abdel- Razek [7]. The start of the combustion process is remarkably advanced. This is due to the higher surface to volume ratio of MWCNT, which enhances the heat transfer between the particles and the fuel droplets which in turn improve the fuel droplet atomization and the combustion process. The addition of nanoparticles improves the heat reaction and increases the peak pressures. These results have a good agreement with that cited in the literature [9 -11].

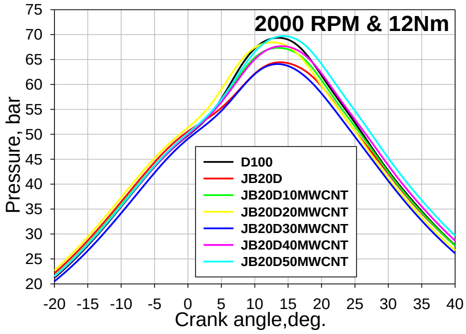

Fig.2. The variation of cylinder pressure with crank angle at 2000 RPM and 12 Nm load for different tested fuel

5.2 Engine Emission Characteristics

From Figure 3, it can be observed that the NO_x emissions using JB20D at 2000 RPM are considerably higher than those recorded when D100 is used no matter the engine load. This behavior may be owed to the increase of oxygen content in JME (since it contains 13% O_2) and so the increase in the reaction temperature leading to an increase in NOx emissions. These results have a good agreement with Radwan et al. [5] and Shehata & Abdel Razek [7]. Also, the NOx emissions due to the additives of nanoparticles are much lower than the corresponding values for both diesel and JB20D blended fuels no matter the engine load. This effect is related to the catalytic behavior of nanoparticles that accelerates the reaction to be completed forming the final products (heterogeneous combustion) with a minimum thermal breakdown of the hydrocarbon compounds, and so the existence of lower active radicals lowering the possibility of forming thermal NOx. This catalytic behavior is decreased as the engine load, and hence cylinder temperature is increased, and so the existence of greater chance for thermal NOx formation. Correspondingly, the minimum NOx emissions are obtained at nano-additives of 20 mg/l for all loads. This result is confirmed by Sajith et al. [10].

Also, Figure 3 represents the emissions of CO and UHC. They have a similar tendency as being a function of engine load and tested fuel. The use of JB20D leads to a remarkable increase in both CO and UHC concentration compared with conventional diesel fuel. This effect may be owed to the longer delay period and higher values of viscosity of JB20D that disturb the fuel atomization and vaporization and so longer time is required to attain complete combustion. Another viewpoint is related to the improper combustion of layers adjacent to the cylinder wall. These layers would contain a larger fraction of hydrocarbons which escaped from the denser and longer-penetrated fuel spray in case of JB20D, and so more UHC is emitted in the exhaust gasses. The nanoparticle additives have a remarkably positive effect on CO and HC emissions. The reason for this may be due to the short ignition delay and the improved ignition characteristics of MWCNT and the high catalytic activity of nanoparticles owing to their higher surface to volume ratio and enhancing fuel-air mixing in the combustion chamber [12]. The best reduction of CO and UHC emissions is attained at doses of nanoparticles (20-40 mg/l).

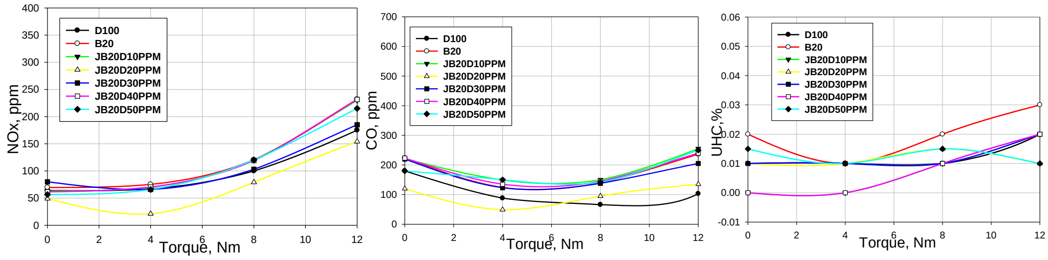

Fig.3. The variation of NOx, CO, UHC emissions with engine torque at 2000 RPM

6. Conclusion

The combustion and emission characteristics of diesel, JB20D blended fuel and JB20D with the addition of MWCNT are investigated for a single cylinder direct injection diesel at a constant engine speed with different loads conditions. The conclusions of this investigation are as follows:

- The used recommended JB20D fuel blend was found to have a negative effect on the engine performance (leading to lower P_{max}, and a higher level of emissions of NO_x, CO, and UHC).
- The peak pressure is higher for the MWCNT addition into JB20D blended fuels due to shorter ignition delay compared to that of JB20D blended fuel.
- The NO_x, UHC, and CO emissions have a marginal reduction when using the MWCNT addition into JB20D blended fuels compared to that of JB20D blended fuel.
- The best mechanical performance has been obtained at nano dose level of 50 mg/l, while the best environmental performance is recorded at a dose level of 20 mg/l.
- The recommended dose level to obtain the significant improvement in all engine performance is 40 mg/l.

The results of the current study would recommend the nanoparticles dose level that improves the performance of the engine fuelled by biodiesel-diesel blended fuels. This improvement helps in increasing the biodiesel blending ratio in the biodiesel-diesel blended fuels and reduces the energy and environmental problems resulting from using the fossil fuels.

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