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Investigation of the Performance and Emissions of an Engine Operated with CEO_2 Nano Additive Doped Biodiesel

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Abstract

The production of greenhouse gases such as carbon dioxide causes global warming and many other environmental problems. Diesel engines are widely used due to their higher output torque value, better thermal efficiency and durability compared to gasoline engines. Because of rapid consumption and mitigation of diesel as a fossil fuel, biodiesel has recently received significant attention as a renewable energy source. There are several sources in order to produce biodiesel. Animal fats, inedible vegetable oils, waste oils and other low-value bioenergy raw materials are suitable sources for biodiesel production as they are renewable and have no impact on food safety. In this study, CeO_2 nano additives at concentrations of 50 ppm and 75 ppm were added to cottonseed based biodiesel. The experiments were conducted at 4 different load conditions on a 3-cylinder water-cooled diesel engine. According to the test results, it was observed that with increasing nano additive concentration, thermal efficiency was increased and specific fuel consumption was reduced. As well as, the results indicated that CO and soot emissions were reduced, while NOx emissions were increased due to the improvement of the combustion performance caused by CeO_2 nanoparticles.

Keywords: Diesel, Biodiesel, CeO_2 nano additive, Engine performance, Exhaust emission

Research Article

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1. Introduction

Internal combustion engines (ICE) will continue to be widely used in power generation and transportation industries over the next decade. According to the scientific research, even by 2040, about 90% of global transportation energy will be obtained from internal combustion engines operating on fossil fuels. This situation leads to serious problems in terms of environmental pollution and energy supply [1]. The reduction of carbon footprint of the ICE has focused on reducing the consumption of fossil fuels [2]. For this purpose, many different alternative fuels have been developed until today. Synthetic fuels produced from hydroprocessed bio-oils, fuels produced from genetically engineered microbes, and biodiesel fuels are several examples of alternative fuels [3]. Biodiesel as one of the most promising alternative fuels has the potential to reduce the consumption and greenhouse gas effect of petroleum based products. It is mainly produced from edible plant oils such as rapeseed, palm and so forth. However, studies in recent years have shown that using these raw materials threatens global food security. So the production of biodiesel from non-edible raw materials such as algae, waste oils, plastic and tire oils has been studied recently [4-6]. Biodiesel is renewable, biodegradable, environmentally friendly, and non-toxic and also has the potential to reduce most of the pollutants emissions thanks to its clean combustion [7-8]. The presence of oxygen in bound of biodiesel fuel increases the combustion efficiency [9]. The biggest disadvantage of biodiesel fuel is that it has a higher density and viscosity in comparison with diesel fuel. To overcome these problems, fuel additives are added to biodiesel in order to improve fuel properties and enhance the quality of combustion. Nano additives are widely used in diesel engines as catalysts because they improve thermal and chemical reactions. Nano additives have gained great interest recently due to their unique physical and thermal properties. Nanoparticles offer many advantages including the diffusion coefficient, large surface/volume ratio and high reactivity. Although, the addition of metal nanoparticles to fuel improves its properties, but it also leads to the production of hazardous substances in the chemical reactions which are harmful for human health and other ecosystems [10]. Due to many superior properties of nano additives, they increase the burning rate. In addition, they improve the reaction efficiency of the fuel. [11]. Since the properties of the fuels influence the atomization quality, it is important to increase the burning efficiency. The interaction between the fuel spray and the surrounding gas is influenced by fuel properties [12]. In this study, CeO_2 nano additive was added to biodiesel fuel to improve its specifications and enhance the combustion efficiency. Due to its excellent catalytic properties, CeO_2 is a popular additive. The oxygen storage capacity of cerium and the high specific surface area of CeO_2 ensure high reactivity [13]. CeO_2 nano additive decreases the temperature of carbon burning, increases hydrocarbon oxidation and promotes complete combustion [11]. Adding CeO_2 catalyst to diesel, increases combustion efficiency and reduces soot emissions [13]. The aim of this study is improve of fuel features, engine performance and emissions of biodiesel fuel with CeO_2 nano additive. The effect of CeO_2 nano additive to related parameters was experimentally investigated and presented in paper.

2. Material and Methods

The biodiesel used in this study (cotton seed biodiesel-C0) was obtained from cotton oil through the transesterification method. In the transesterification process, methanol and NaOH catalyst were used. Cottonseed oil was first preheated to 110 °C in order to remove any water from the oil. Then, transesterification reaction was carried out at 60±1 ºC. After 1 hour of reaction, the mixture was set aside for 8 hours for the separation of glycerin and crude biodiesel. After separating biodiesel from glycerin, biodiesel was washed with distilled water and then dried at 110 °C. After the washing and drying processes, nanoparticles were added to the biodiesel. The weight percentage of nano additive was measured by a digital scale and then the nano additive was mixed with the fuel at 50ppm (Ce-50) and 75ppm (Ce-75) ratios using the ultrasonic stirrer. The specifications of test fuels are presented in Table 1. The experimental setup is shown in Fig. 1. The experiments were conducted on a three-cylinder, water cooled, four-stroke, LDW 1003 Lombardini diesel engine. The technical specifications of the test engine are given in Table 2. The test engine was connected to Net Brake NF150 hydraulic dynamometer. A CAS-SBA 200L model load cell was used to measure the torque up to 450 Nm in the speed range of 0-6500 rpm. Cylinder pressure was measured by PCB 113B22 piezoelectric pressure transducer and recorded every 1 degree of crank angle for 100 cycles, and then the in-cylinder pressure mean values were calculated. Bosch BEA 060 and Bosch BEA 070 emission devices were used for the measurement of the exhaust emissions. Elimko BT01 K Type Ni-Crocouple thermocouple was used to measure exhaust temperatures. It can read to temperatures between the -40 to 375 ºC with precision of +/- 1.5 ºC and 375 to 1200 ºC with 0.4%. The thermocouple was mounted 70 mm ahead of the exhaust port.

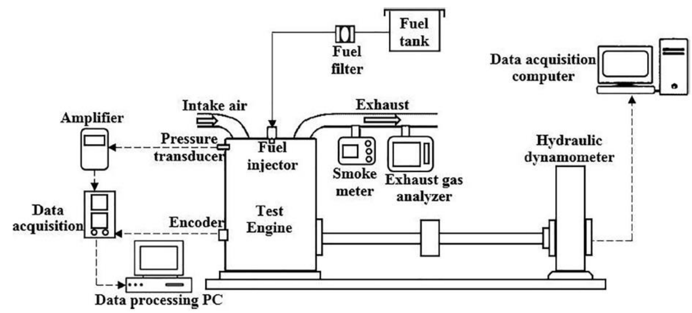

Fig. 1. Experimental setup

Table 1. Specifications of test fuels

	Density (15 ºC) (kg/m³)	Viscosity (40 ºC) (mm²/s)	Flash Point (ºC)	Lower Heating Value (Mj/kg)
C0	886	4.6	175	38.80
Ce-50	865	4.4	168	38.94
Ce-75	849	4.1	157	39.18

Table 2. Technical specifications of the test engine

LDW 1003 Lombardini	Technical Specifications
Number of cylinders	3
Diameter x Stroke (mm)	75 x 77.6
Total cylinder volume (cm³)	1028 cm³
Maximum speed (rpm)	3600
Maximum power (kW)	19.5
Maximum torque(Nm)	67
Compression ratio	22.8:1
Injection advance	10°
Injection static timing (°BTDC)	8-10
Static timing method	Low pressure
Special tools tor TDC,timing and pressure testing	Timing/Pressure-1460.074 TDC-1460.048
IVO/IVC	16 °CA BTDC/36 °CA ABDC
EVO/EVC	36 °CA BBDC/16 °CA ATDC

3. Results and Discussion

3.1. Specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) with load for test fuels is shown in Fig. 2. It was observed that the brake specific fuel consumption decreases with increase in load. As well as, the BSFC was reduced with increasing the dosing level of CeO_2 nanoparticles to biodiesel. At engine load of 40 Nm, the BSFC for C0, Ce-50 and Ce-75 were 253.36, 243.76 and 242.89 g/kWh, respectively. The lower BSFC is attributed to the lower density and viscosity, and higher calorific value [14]. The maximum reduction of brake specific fuel consumption was 5.13% for Ce-75 fuel compared to C0 fuel at engine load of 10 Nm. Nanoparticles have high surface area and can provide better surface reactivity. The addition of nanoparticles to fuel can also enhance the thermo-physical properties. Adding nanoparticles to C0 fuel decreases the viscosity of fuel which can reduce the size of the fuel droplets and increase the burning efficiency and consequently reduce BSFC [15]. Moreover, CeO_2 nano additive contains oxygen that leads to an increase in the heating value of the fuel and therefore it has a positive effect on the BSFC [16].

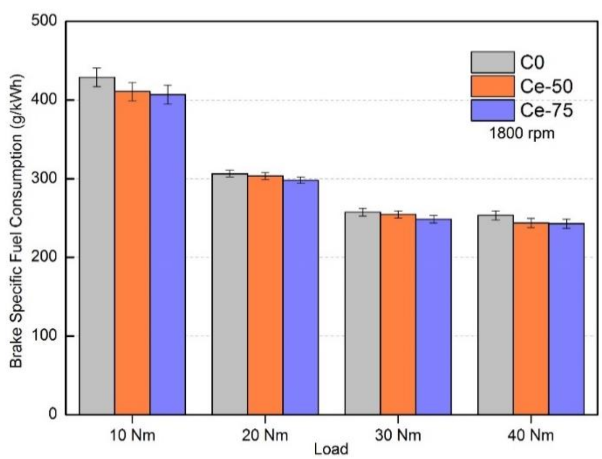

Fig. 2. The variation of BSFC with load for blends of cotton biodiesel with nanoparticles

3.2. Thermal Efficiency

Thermal efficiency represents the combustion performance in the cylinder. Studying the thermal efficiency is important, because it describes the efficiency of the engine. Better spray and atomization properties of fuel improve the thermal efficiency [17]. Thermal efficiency increases as BSFC decreases, because they are inversely proportional. Fig. 3 shows the thermal efficiency variation with load for test fuels. The thermal efficiency was 37.5% for C0 fuel at full load. It increased by 3.39% and 2.87% respectively for Ce-50 and Ce-75 compared to C0 fuel. The increase in thermal efficiency is due to the micro-explosions that occur as a result of the nanoparticles dispersed in the fuel droplets. The nanoparticles provide improved air-fuel mixing and enhanced chemical reactivity during combustion [17]. As well as, the nano additive acts as a catalyst by providing oxygen olecules that causes the complete combustion of carbon monoxide and unburned hydrocarbons [18].

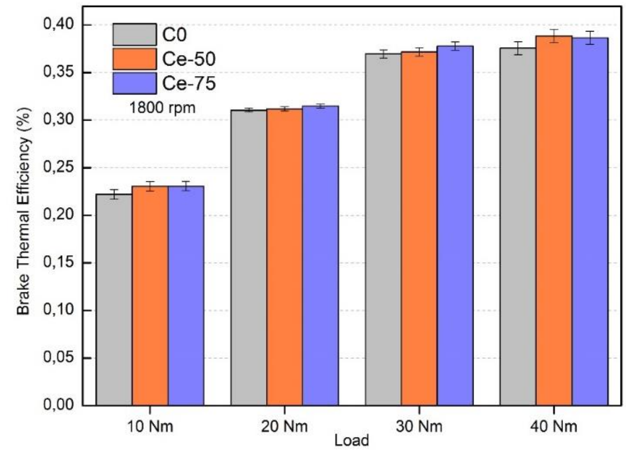

Fig. 3. The variation of BTE with load for blends of cotton biodiesel with nanoparticles

3.3. Exhaust Gas Temperature

The study of exhaust gas temperature (EGT) is of extreme importance, as it gives an idea about the formation of harmful emissions in the engines. However, the EGT is a serious indicator of the temperature in the post-burning phase. EGT varies according to fuel specifications and engine operating conditions [19]. Fig. 4 shows the EGT variation with load for test fuels. It was observed that the EGT increased with increasing of load and the concentration of nanoparticles. At engine load of 40 Nm, the EGT were 317 ºC, 323 ºC and 342 ºC respectively for C0, Ce-50 and Ce-75. At lower load conditions, the increase percentage of the EGT was higher, because the addition of nanoparticles improved the engine combustion. The maximum increase was 15.71% for Ce-75 fuel in comparison with C0 at engine load of 10 Nm. The addition of nanoparticles to fuel improves the atomization specifications and thereby enhances the combustion efficiency due to the better viscosity and density values. This condition affects the formation of high combustion temperatures in the cylinder.

3.4. Cylinder Pressure

Fig. 5 shows the maximum cylinder pressure variation with engine load, while Fig. 6 illustrates the cylinder pressure at engine load of 40 Nm. By adding CeO_2 nanoparticles to fuels, the cylinder pressure increases. The maximum cylinder pressure was 59.73 bar for Ce-75 fuel. As a result of the nanoparticles addition, density and viscosity values of the fuels decrease and the amount of oxygen in the fuels improves. This condition positively influences the physical processes such as atomization, heating, evaporation and mixing in the cylinder [20]. Because the high viscosity of fuel minimizes the fineness of atomization, the spraying properties are greatly affected [21]. Decreasing the viscosity and density results in the improvement of combustion efficiency and thereby causes an increase in cylinder temperature and consequently the exhaust gas temperature [22]. In addition, the active Ce atoms released from CeO_2 cause hydrogen formation in high cylinder temperature [23].

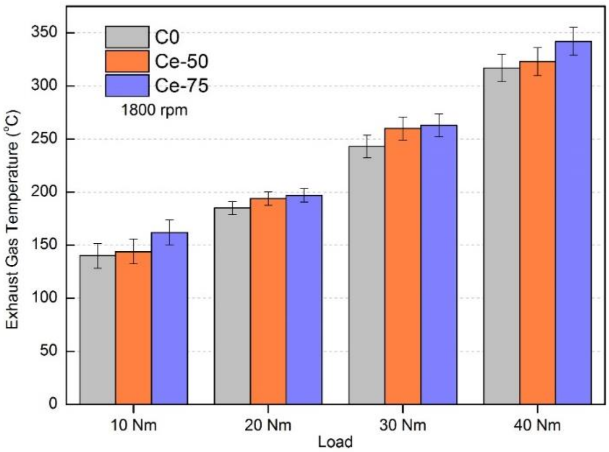

Fig. 4. The variation of EGT with load for blends of cotton biodiesel with nanoparticles

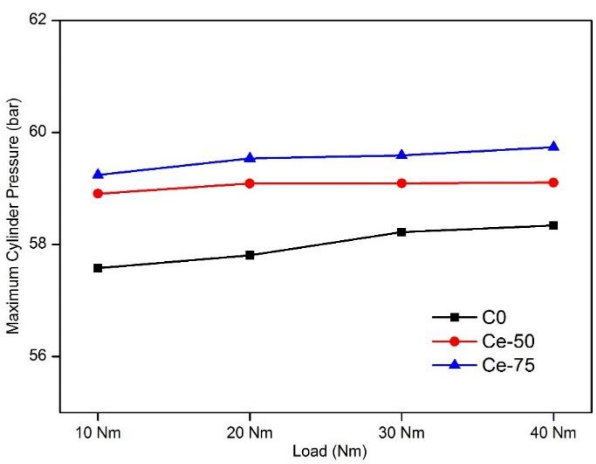

Fig. 5. Maximum cylinder pressure variation with engine load

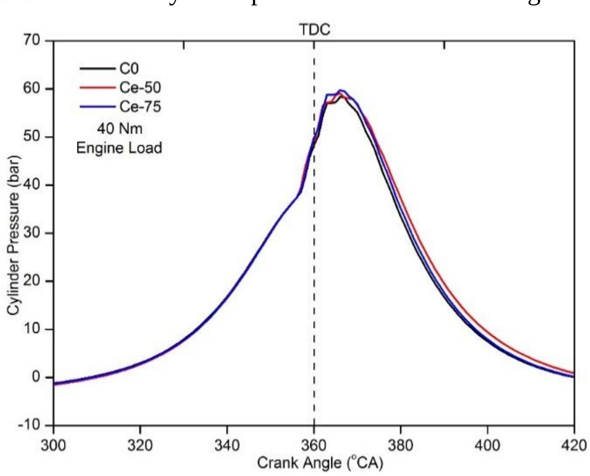

Fig. 6. Cylinder pressure (40 Nm Load)

3.5. Carbon monoxide (CO) and Carbon dioxide (CO_2) Emissions

CO emission is affected by several factors such as air-flow rate, atomization, oxygen-carbon contents, injection timing, etc. Nanoparticles act as O_2 buffers by giving oxygen and perform as catalysts. It helps to achieve improved oxidation during combustion that leads to lower CO emission. In addition, large surface-volume ratio of nanoparticles increases chemical reactivity resulting in complete combustion and less CO emissions [24]. Secondary atomization, assisted by the microburst of CeO_2 in fuel blends, minimizes the formation of fuel-rich areas and leads to the reduction of CO emissions [13]. Fig. 7 and Fig. 8 show the variation of CO and CO_2 emissions with engine load, respectively. With the addition of CeO_2 nanoparticles to biodiesel fuel, CO emissions were reduced while CO_2 emissions increased at all load conditions. Nano additives act as oxygen donor catalysts [25].

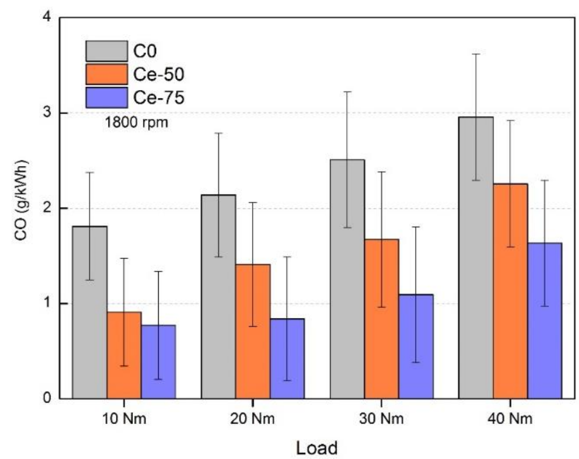

Fig. 7. The variation of CO emissions with load for blends of cotton biodiesel with nanoparticles

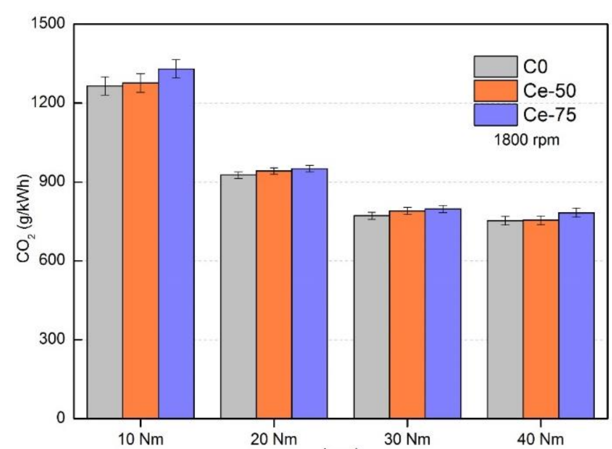

Fig. 8. The variation of CO_2 emissions with load for blends of cotton biodiesel with nanoparticles

At engine load of 40 Nm, the CO emissions were 23.70% and 44.75% lower for Ce-50 and Ce-75 fuels respectively compared to C0. At the same load condition, CO_2 emissions increased by

0.22% and 4.06% respectively for Ce-50 and Ce-75 compared to C0 fuel. The increase of oxygen content in the fuel increases CO_2. CO_2 emission level is an important indicator of combustion efficiency [26]. Moreover, when carbon molecules are burned, CO_2 is formed as an end product of combustion due to high post-combustion temperature. This means that there is enough oxygen for oxidation which leads to achieve complete combustion and to produce CO_2 in the exhaust [19].

3.6. NOx and Smoke Emissions

NOx and smoke are two significant emissions from diesel engines. They have a close relationship that is called trade-off [27]. Simultaneous reduction of smoke and NOx is very difficult due to inhomogeneous of fuel-air mixture and temperature in the combustion chamber [28]. Smoke is usually a result of incomplete combustion [25]. At temperatures above 1800 K, molecular N_2 and molecular O_2 participate in a series of reactions that result in the formation of NOx [29]. Fig. 9 and Fig. 10 show NOx and smoke emissions variation with load, respectively. The fuel additive and high oxygen content of the fuel result in an increase in the combustion efficiency which leads to higher in-cylinder pressure and thereby higher NOx emissions [30]. At engine load of 40 Nm, the NOx emissions were 0.85% and 1.88% higher for Ce-50 and Ce-75 fuels respectively compared to C0. Smoke emissions decreased by 23.78% and 28.71% respectively for Ce-50 and Ce-75 compared to C0 fuel at the same load condition. As temperature in the combustion chamber rises, NOx emissions increase. On the other hand, smoke emissions were found to be lower at high cylinder temperature [31]. Nanoparticles act as oxygen supplier and improve the heat transfer. They also reduce smoke emissions by increasing the oxidation of particles at higher temperatures [32]. Since the oxygen region connected to the fuel increases with the addition of nanoparticles, this leads to the reduction of smoke emission [33].

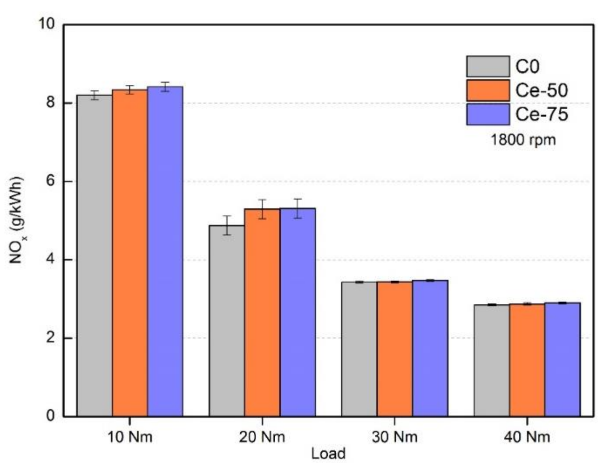

Fig. 9. The variation of NOx emissions with load for blends of cotton biodiesel with nanoparticles

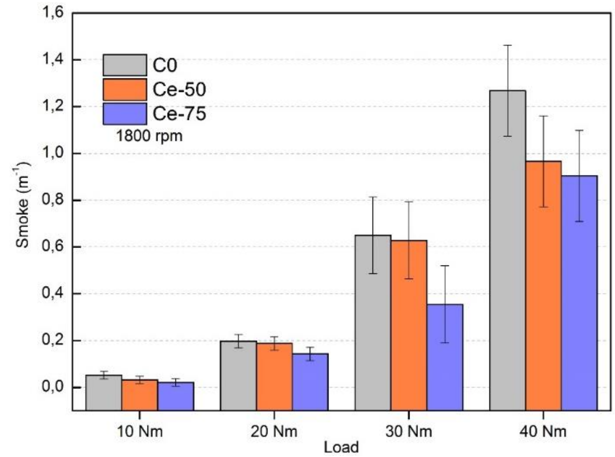

Fig. 10. The variation of smoke emissions with load for blends of cotton biodiesel with nanoparticles

4. Conclusions

In this study, the effect of adding CeO_2 nano additive to cotton based biodiesel on the engine performance and emission characteristics was investigated. The nanoparticles as a fuel additive is gaining much attention, because it has the potential to promote fuel oxidation, increase the burn-up rate and enhance the engine performance due to its catalyst effect. According to the results, the brake specific fuel consumption decreased by 3.78% and 4.13% respectively for Ce-50 and Ce-75 compared to C0 at engine load of 40 Nm. At lower load conditions the change of thermal efficiency was higher. At engine load of 10 Nm, the thermal efficiency was 3.86% and 3.96% higher for Ce-50 and Ce-75 fuels respectively compared to C0. It was found that the nano additives improve the evaporation rate of fuel droplets. The CeO_2 nano additive improves the heat transfer rate and has the positive influence on the emissions of several major environmental pollutants. The reduction in CO and soot emissions was higher at lower load conditions. At engine load of 10 Nm, the CO emissions were 63.70% and 69.21% lower for Ce-50 and Ce-75 respectively compared to C0. At the same load condition, the reduction in soot emissions were 38.04% and 59.88% for Ce-50 and Ce-75 respectively in comparison with C0. NOx emissions were higher due to improved combustion at lower load conditions. NOx emissions increased by 1.66% and 2.65% respectively for Ce-50 and Ce-75 compared to C0 fuel at engine load of 10 Nm.

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Nomenclature

Internal combustion engines	ICE
Cetane number	CN
Diesel engine	DE
Brake Specific fuel consumption	BSFC
Brake Thermal efficiency	BTE
Cotton seed biodiesel	C0
Exhaust gas temperature	EGT
Top dead center	TDC
Bottom dead center	BDC
Intake valve open	IVO
Intake valve close	IVC
Exhaust valve open	EVO
Exhaust valve close	EVC

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

CRedit Author Statement

Mehmet Celik: Investigation, Writing - review & editing, Data analysis, Writing - Original draft, Conceptualization,
Cihan Bayindirli: Investigation, Visualization, Writing - review & editing, Writing - original draft
M. İlhan İlhak: Investigation, Methodology, Writing - original draft

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