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Original Research Article

Investigation of Effect of n-hexane Additives in Biodiesel in Combustion and Exhaust Emissions in Diesel Engines

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Abstract

There are various studies concerning biodiesel fuel and its spraying, combustion and emission properties within the diesel engines. In the diesel engines, the hazardous emissions such as carbonmonoxide (CO), carbondioxide (CO_2), hydrocarbon (HC) and particle matter (PM) decreased along with the use of biodiesel. But a slight increase in azotoxit (NO_x) emissions was observed due to the use of biodiesel which is an oxygenated fuel. In this study; by volume 4% 12% and 20% n-hexane were added in biodiesel which produced by transesterification method from cottonseed oil. Engine tests were carried out at 6 min-1. The maximum moment obtained at 1400 min-1. The maximum increase in moment is 3.95% in CHX20 fuel, while the specific fuel consumption is reduced by 5.52%. At 1400 min-1, the maximum of cylinder pressure and heat dissipation is increased by increasing of additive ratio. As the n-hexane ratio increases, the emissions of CO, HC and smoke decrease while NO_x emissions increase.

Keywords: Biodiesel, Fuel Additives, Combustion, Engine Performance, Exhaust Emissions

Nomenclature and abbreviations

C0	Cotton methyl ester
CHX4	96% cotton methyl ester + 4% n-hexane
CHX12	92% cotton methyl ester + 8% n-hexane
CHX20	88% cotton methyl ester + 12% n-hexane
TDC	Top dead center (ºCA)
HC	Hydrocarbon (ppm)
NO_x	Nitrogen oxides (ppm)
CO_2	Carbon dioxide
CO	Carbon monoxide (%)
PM	Particle matter
CA	Crank angle, (degree)
NaOH	Sodium hydroxide

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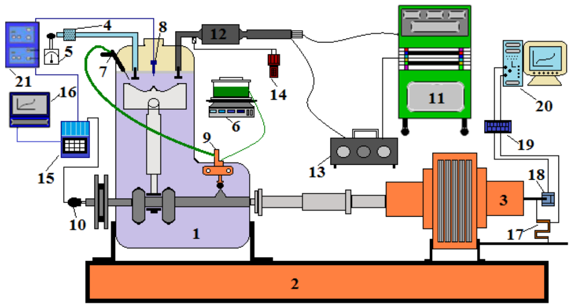
1. Introduction

The interest to diesel engines increases each year due to their high efficiency, better fuel economy and low emission [1]. Diesel engines are widely preferred in industrial and agricultural applications and transportation due to the high levels of efficiency and reliability they provide [2]. Thus, the demand for diesel fuel increases in the world each year [1]. Diesel engines generate significant degrees of nitrogen oxides (NO_x) and particulate matter (PM) pollutant emissions. Significant researches are being performed in order to decrease the emissions and fuel consumption based from diesel engines. By the engine design studies, the emissions and fuel consumption had been significantly decreased. However, it is hard to obtain the required results only by the engine design studies [3]. Due to constantly increasing anxiety for diesel emissions-oriented adverse health effects, pollutants which are contain hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM) have been enacted in many developed countries [4]. The US Environmental Protection Agency (EPA) has approved Euro VI standards and has stated that NO, CO and PM emission rates must be reduced respectively by 25%, 24% and 10%, by 2030 [5]. The growing environmental and health concerns towards the consumption of petroleum resources has necessitated the development of alternative from renewable resources which are cheaper and acceptable with respect to the environment [6]. Alternative fuels should be renewable, antipollutionist and easily obtainable energy sources. In addition, they should be able to be used in internal combustion engines through a few modifications [3]. Biodiesel, which exhibits combustion properties similar to diesel fuel, is of interest to researchers [7]. Biodiesel is able to be used by adding in the diesel fuel as well as directly being used in engines [8]. Currently, 10% of the diesel fuel requirement of the world is being met from biodiesel. It is being expected for this rate to increase due to petroleum prices and environmental effects [9]. Today, the production of biodiesel has significant economic and social effects on the development level of especially developing countries [10]. The physical and chemical properties of the fuel used in internal combustion engines affect fuel economy and emission characteristics [11]. Biodiesel has a high viscosity and density compared to diesel fuel; through research conducted, it has been specified that high viscosity and density reduces spraying quality and as a result, the average droplet diameter and disintegration period of the fuel spraying increases [12]. Different additives were added to the fuel to aid the physical properties of the fuel, improve the combustion, and decrease the emission of harmful exhaust gases. These additives form a catalytic effect which enhances the combustion of the hydrocarbons [13]. With the use of additives, the performance, combustion and emission characteristics of the fuel may be improved. Conducted studies indicate that additives reduce ignition delay and specific fuel consumption while increasing the thermal values of the fuel [14]. In diesel engines, proper fuel atomization enables higher efficiency and significantly reduces exhaust emission generation. Ignition, combustion and pollutant emission generation are affected by atomization properties [15].

The aim of this study is to improve the adverse fuel properties that limit the use of biodiesel. Fuel properties such as density, viscosity, glow point and thermal value of biodiesel negatively affect combustion. The biodiesel which was used in the experiments was produced by transesterification from cottonseed oil. NaOH was used as the catalyst and methanol was used as the alcohol. The reaction was carried out at 60 ± 1 °C for 1 hour. After separation of biodiesel and glycerin, washing and drying were carried out. In preparation of the test fuels, 4% (CHX4), 12% (CHX12) and 20% (CHX20) of n-hexane additives were added to cotton methyl ester (C0). n-hexane is an alkane hydrocarbon with the chemical formula $CH_3(CH_2)_4CH_3$ or C_6H_{14}. The "hex" prefix refers to its six carbons, while the "ane" ending indicates that its carbons are connected by single bonds. Hexane isomers are largely unreactive, and are frequently used as an inert solvent in organic reactions because they are very non-polar [16]. The properties of the fuels which the additive is added are given in Table 1. Engine tests were carried out at fixed engine operating temperatures at six different min-1, ensuring stable operating conditions. It is aimed to improve the fuel properties and the related performance and emission characteristics by adding n-hexane additive in methyl esters.

2. Experimental Setup

In the study, a diesel engine with single cylinder was assembled to hydraulic dynamometer test system. Schematic illustration of experimental setup is given in Figure 1. The values obtained during the loading of engine, were read by using CAS branded SBA 200L model load cell that is capable of measuring within 0-200 kg range as having sensitivity for 1 g. Speed measurement range for dynamometers is 0-6500 min-1 and torque measurement interval is 0-450 Nm. Technical features as relating with experimental engine are presented in Table 2.



1. Test engine, **2.** Platform, **3.** Hydraulic dynamometer, **4.** Air-intake, **5.** Flowmeter, **6.** Balance, **7.** Diesel injector, **8.** Cylinder pressure sensor, **9.** Diesel fuel pomp, **10.** Encoder, **11.** Bosch gas analyzer, **12.** Exhaust pipe, **13.** Opacimeter, **14.** MRU gas analyzer, **15.** Data acquisition system for combustion analyzes, **16.** PC for combustion analyzes, **17.** Load - cell for engine torque, **18.** Engine speed sensor, **19.** Data acquisition system for engine performance, **20.** Engine test controller, **21.** Amplifier.

Figure 1. The schematic view of the engine test system

Table 1. Characteristics of test fuels

	Viscosity (mm^2/s, 40°C)	Density (kg/m^3, 15 °C)	Lower Heating Value (MJ/kg)	Cetane Number
	ASTM D 445	ASTM D 1298	ASTM D 2015	ASTM D 6751
C0	4.64	0.886	38.69	57.1
CHX 4	4.05	0.878	38.82	55.5
CHX 12	3.02	0.858	39.05	52.6
CHX 20	2.34	0.843	39.25	50.7
n-hexane	0.51	0.650	---	44.8

Table 2. Technical specifications of the test engine

Make/Model	Antor/3 LD 510
Engine type	DI-Diesel engine, Four stroke, Water cooling
Cylinder number	1
Bore x stroke [mm]	85 x 90
Displacement [cm^3]	510
Compression ratio	17.5:1
Maximum torque [Nm]	32.8 @ 1400 min^{-1}

Cylinder pressure was measured by calculating pressure values inside the cylinder obtained for each 1 °CA range along 720 °CA for each work cycle. Pressure values in-cylinder were determined by taking the average of values derived after implementing Savitzky-Golay filtering method for at least 50 cycles. Combustion mechanism is one of the complex phenomena in internal combustion engines. Characteristics of combustion process were shown by using cylinder gas pressure, ignition delaying period, combustion periods and heat release rate. These parameters can be calculated as being based on variation of cylinder pressure data obtained from the engine [17]. Data derived from cylinder pressure sensor during the experimental measurement, are influenced by factors like instantaneous change of cylinder volume and heat transfer to combustion and cylinder wall. During the testing, Bosch-BEA 350 model gas analyzer was used for measuring exhaust emissions and Bosch RTM 430 model smoke measurement kit was used for measuring smoke emission. The device can measure CO, CO_2, HC, and NO_x emissions and smoke opacity as a ratio of volumetric flow rate of exhaust gas (%). Technical features of exhaust gas analyzer are given in Table 3.

Table 3. Technical specifications of exhaust gas analyzers

Measurement	Measurement rates	Sensitivity
CO_2, v/v %	0-18	0.01
CO, v/v %	0-10	0.001
HC, ppm	0-9999	1 ppm
NO, ppm	0-5000	1 ppm
Smoke, %	0-100	0.1

3. Result and Discussion

Figure 2 and Figure 3 show the engine torque and brake power graphs of the fuels to which the additive is added. The maximum engine torque was obtained at 1400 min-1 in C0-CHX4-CHX12 and CHX20 fuels as 33.35, 33.65, 34.15 and 34.67 Nm, respectively. When the maximum brake power was achieved at 2800 min-1 as 7.14 kW in C0 fuel, the maximum power increase was 5.3% in CHX20 fuel. Figure 4 shows that the specific fuel consumption graph of the fuels to which the additive is added. At 1400 min-1 which maximum engine torque is obtained in C0 fuel as 288.61 g/kWh. According to C0 fuel, the specific fuel consumption of CHX4-CHX12 and CHX20 fuels decreased by 1.14% -3.08% and 5.52% respectively. The viscosity, density and cetane number of the fuels which the n-hexane additives is added decrease while the lower heat value increase. The characteristics of the sprayed fuel in diesel engines have a great influence on engine performance [18]. The viscosity and density of the fuels which the additive is added are reduced. The lower heat value increased. This situation increased the spreading of the fuel in the cylinder and improved to atomization characteristics. It is thought that this result increased engine performance and reduced specific fuel consumption [19].

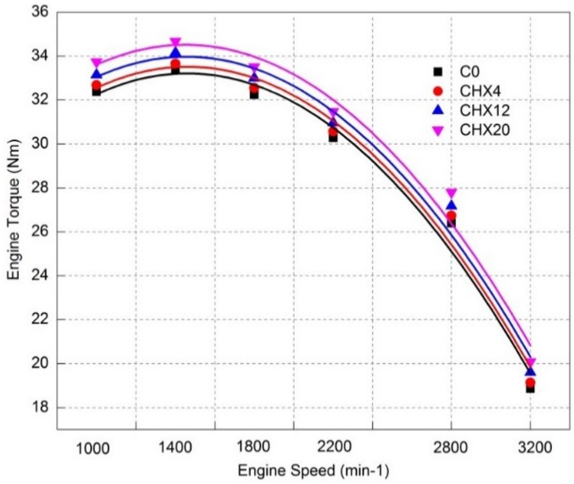


Figure 2. The engine torque graph of n-hexane added biodiesel fuels

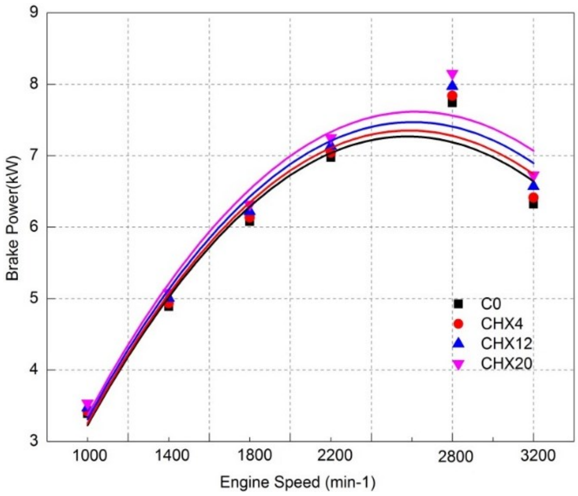


Figure 3. The brake power graph of n-hexane added biodiesel fuels

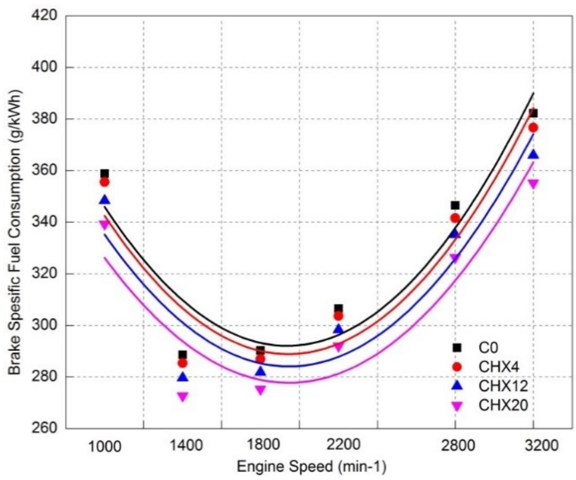


Figure 4. The Specific fuel consumption graph of n-hexane added biodiesel fuels

The graph of cylinder pressure and heat release rate is given in Figure 5. At 1400 min-1, the maximum cylinder pressures of C0-CHX4-CHX12 and CHX20 fuels were respectively 93.55-95.18-97.07 and 98.86

bar. The increase in maximum cylinder pressure can be understood when the viscosity is reduced by breaking the bond between molecules with n-hexane mixture [20]. Maximum cylinder pressure depends on fuel properties such as viscosity, cetane number and fuel volatility [21]. It is seen that the increase in cylinder pressures is coherent with the brake power graph. By adding n-hexane additives in biodiesel, the cylinder pressure increased and the maximum cylinder pressure approached the top dead center. The maximum heat release rate was 0.0269 kJ/ºCA in CHX20 fuel which has additives. The decrease in viscosity causes better evaporation of fuel which includes additives [22]. The increase in the lower heat value of the additive added fuels also causes high cylinder pressures and heat dissipation. The high heat dissipation supports the idea of shortening ignition delay and early start of combustion.

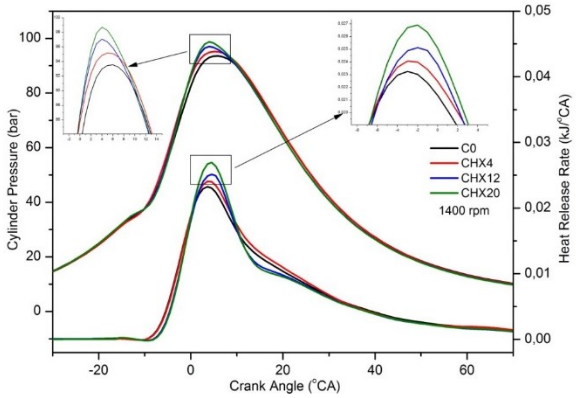


Figure 5. The cylinder pressure and heat release rate graph of n-hexane added fuels

CO and HC graphs are given in Figures 6 and 7. CO and HC emissions decreased with the increasing of min-1, but they started to increase again at 2800 min-1, after maximum brake power was obtained. In all speeds, CO and HC emissions decrease with increasing n-hexane ratio. Compared to C0 fuel, the maximum CO reduction was obtained in CHX20 fuel as 14.65%, while the HC emission increased to 23.33% at 2800 min-1. The CO emission depends on the quality of the combustion. The decrease in density and viscosity by adding n-hexane, causes the decrease of the droplet diameter of fuel. It absorbs less heat in the cylinder for fuel evaporation [23]. As the decrease of viscosity and density, the combustion and spraying quality increase. CO and HC emissions decrease with additive added in the fuels.

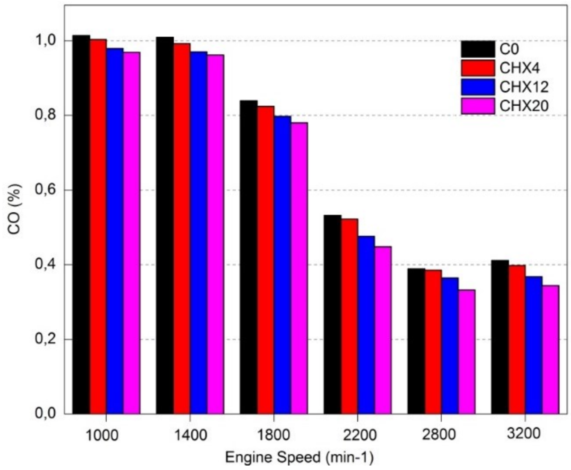


Figure 6. CO emission graph of the n-hexane added fuels

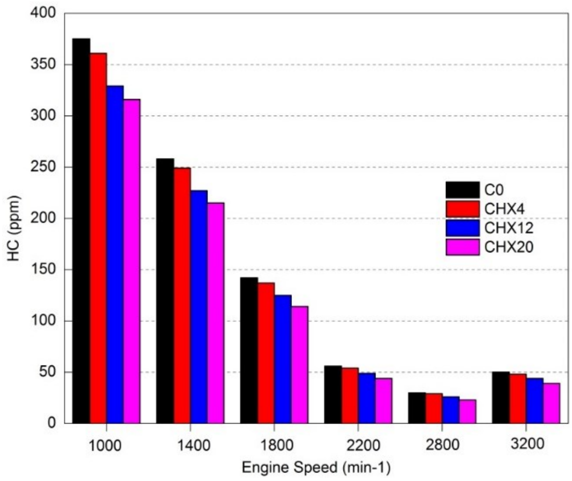


Figure 7. HC emission graph of n-hexane added fuels

Figure 8 shows the NO_x emission graph. As the n-hexane ratio increases, NO_x emissions also increase. The maximum increase in NO_x emissions has been 4.83% in CHX20 fuel at 3200 min-1 compared to C0 fuel. NO_x emission is formed with chemical reaction of N and O atoms at very high temperature in cylinder [24]. With the combining of different molecules of nitrogen and oxygen gases, various gases emerge, and all of them are called as “Nitrogen oxides” and expressed as NO_x [25]. If n-hexane is added to the fuels, cylinder pressure and heat release rate increase, this supports increase in NO_x emissions.

Figure 9 shows smoke emission graph. The maximum brake power was obtained at 2800 min-1. The decrease in smoke emission in CHX4, CHX12 and CHX20 fuels was 5.60%, 11.68% and 16.35%, respectively according to C0 fuel. The high density and viscosity of the fuel negatively effects on combustion quality, atomization and evaporation in cylinder [26]. Due to the improved fuel properties by adding n-hexane in biodiesel, during the combustion the oxidation temperature decreases and there is a significant decrease in the soot emission.

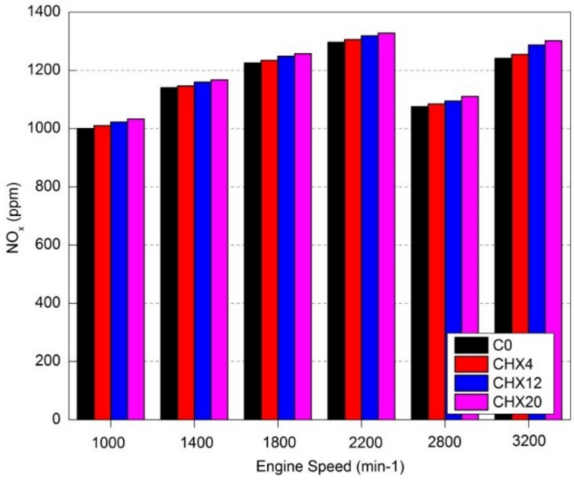


Figure 8. NO_x emission graph of n-hexane added fuels

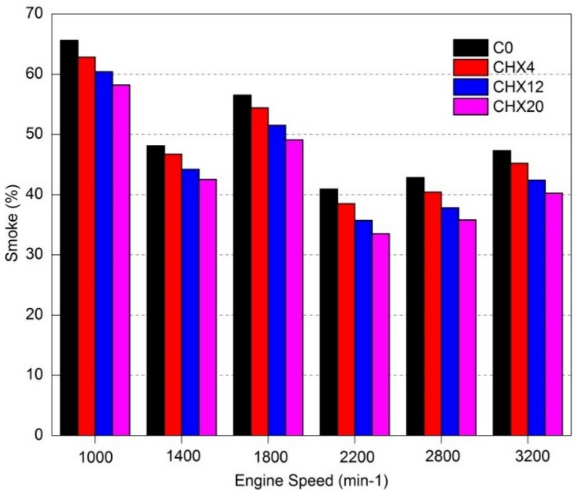


Figure 9. Smoke emission graph of n-hexane added fuels

4. Conclusions

By adding n-hexane in biodiesel, the viscosity, density and cetane number of the fuels decrease while the lower heating value increases. Depending on the change in fuel properties, brake power and engine torque increase while specific fuel consumption decreases. With the decrease in the cetane number of fuel, the increase of ignition delay is expected and the cylinder pressure is decreased. However, due to the improvement in viscosity and density, the cylinder pressure and heat release rate have increased. As the n-hexane additive rate increases, the combustion characteristics improve and NO_x emissions increase, while CO, HC and work emissions reduce at all speeds. Although the performance and emission values of the n-hexane added fuels are positive, the usability limits of the fuels should be considered while determining the additive rate.

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