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Experimental Investigation of Effect of n-Hexane Addition in Diesel and Biodiesel Fuels on Performance and Emissions Characteristics

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Abstract

The chemical property of fuel seriously affects it's the spray and atomization. Better atomization contributes to higher efficiency and less exhaust emissions. Fuel characteristics can be improved by addition of additives in the fuel. In this study, n-hexane additive was added in diesel and two different biodiesel fuels. The additive decreased the cetane number, density and viscosity values of the test fuels while increased the lower calorific value. As a result of the experiments, it was seen that there was an increase in the engine torque, engine power and specific fuel consumption by adding additives. Engine torque increased by 1.09% in DHX16 fuel compared to D0 fuel, 5% in RHX16 fuel compared to R0 fuel and 3.29% in CHX16 fuel compared to C0 fuel. The ignition delay decreased with additives and the cylinder pressure increased. The reduction in CO emissions was 7.07% in DHX16 fuel, 12.86% in RHX16 and 12.85% in CHX16 fuel. This decrease in HC emissions was 17.04%, 18.42% and 16.66%, respectively. In terms of NO_X emissions, there was an increase of 4.73% in DHX16 fuel mixture compared to D0 fuel, 0.98% in RHX16 fuel mixture compared to R0 fuel and 2.01% in CHX16 fuel mixture compared to C0 fuel due to the improvement of combustion.

Keywords: Biodiesel, Combustion, Fuel additive, Engine performance, Exhaust emissions.

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1. Introduction

In today's world, energy is indispensable for daily life, agricultural, industrial and transportation due to different using [1]. Energy is one of the most important factors that effect on daily life. As the world population, economic activities and living standards increase, requirement to energy resources increases. Big percent of energy demands are met from fossil sources [2]. The using of diesel engines is very popular due to their durability and fuel economy in industrial applications. The combustion in the cylinder occurs at high temperatures in diesel engines. Therefore, NOX and PM emissions are inevitable in the combustion process. Since these emissions pose serious problems especially in terms of greenhouse gas effect and human health. The regulations regarding these emissions of diesel engines are happening stricter worldwide [3]. Using of fossil fuels forms environmental threat in the form of climate change and global temperature. For these reasons, countries plan to use clean and renewable energy. Requires from EU members to using 10% of renewable fuel in transportation by 2020 [4]. Biodiesel it can produce from domestic energy sources, it does not include toxic effect. Compared with diesel fuel, it has suitable combustion profile with features for example lower carbon monoxide (CO), hydrocarbon (HC) and particulate matter emissions (PM), higher cetane number and lower sulfur content. Thus, the impact of biodiesel combustion on greenhouse gas decreases [5-6].

Biodiesels reduce harmful exhaust emissions. Many studies prove that vehicle-based emissions cause serious health problems in the respiratory [7]. The thermophysical characteristics of fuels are related to atomization, air-fuel mixture rate, combustion, emission, and engine efficiency [8]. It can be improved with the additives added into the properties of alternative fuels [9]. Improvements in fuel properties are positively reflected in engine parameters [10]. The mixture of diesel, biodiesel and alcohol was used in experimental study. The BSFC of fuel mixtures increased between the rates of 4.54% - 27.82% compared to diesel fuel. The total emissions of decreased compared to diesel fuel. Alcohol caused the decreasing of heat dissipation rates

[18]. The effects adding of ethanol, methanol and n-butanol in reference fuel were investigated of combustion performance. Slow flame development has been with adding that additives when compared to reference fuel. It was determined that CO-Vimep reduced with increasing mixture rate. The ID increased of alcohol mixtures. NOX emissions has increased. CO emissions decreased [19]. Elkelawy et al. was obtained three different types of mixed fuel which are B20 and B50 added 2%, 4% and 6% organic compounds into the two main blend fuels, AC2, AC4 and AC6. In the results for B20AC2 fuel, the BTE increased by 12.64% compared. In addition, the exhaust gas temperature decreased by 18.09%. Emissions of CO, CO2, UHC PM decreased by 63.38%, 22.69%, 47.76% and 40.84%, respectively [20]. In another study, the influence of biodiesel and diethyl ether additives in diesel were tested regarding performance of diesel engine. The specific fuel consumption of D70B30 fuel increased while compared to diesel fuel. BTE increased in many loads in DEE (D70B25DEE5) fuel added to diesel-biodiesel fuel [21]. In a study was mixed with methanol and coconut oil in different proportions. In conclusion, the best results M20 fuel. While the maximum power was 3.2 kW for diesel fuel, it was 3.1 kW for M20 fuel. It was stated that this is due to the lower calorific value of blended fuels compared to diesel fuel. Although the thermal value of the blended fuels was low, their BTE was high and BSFC values rised in experiments. The CO emission increased; NOX emission decreased in blended fuels [22]. Öztürk et al. delayed the injection timing to overcome NOX in diesel engines. In the experiments, they used diesel - biodiesel mixed fuel. As a result, it was seen that less NOX emission occurred in 2oCA injection delay. It was observed that further increase in injection timing worsens the test results. 11% reduction in NOX emission and 2.7% reduction in BSFC was obtained in 2oCA injection delay [23].

The aim of this study is experimentally examining the impact of n-hexane additive in diesel fuel, rapeseed, and cottonseed methyl ester on account of engine performance and exhaust emission values. It was aimed to improving of fuel properties then performance values and emissions of fuels with n-hexane additives in diesel and biodiesel.

2. Material and Methods

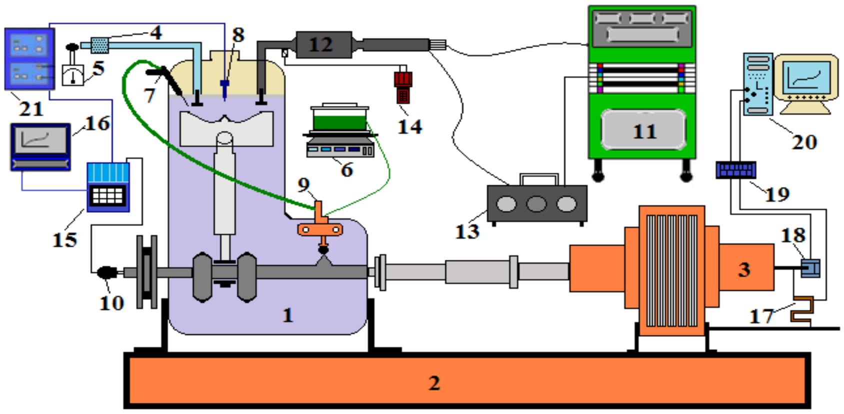
The biodiesels were produced from rapeseed and cottonseed oil by the transesterification method. NaOH and methanol were used in production of biodiesels as catalyst and alcohol by volume. While preparing the test fuels, n-hexane additive was added in diesel (D0), rapeseed (R0) and cottonseed methyl ester (C0) at the rate of 8% (DHX8-RHX8-CHX8) and 16% (DHX16-RHX16-CHX16). The properties of the fuels with additives are shown in Table 1.

Table 1. Properties of test fuels

	Cetane Number	Density (kg/m^3. 15 ^{o}C)	Viscosity (mm^2/s. 40 ^{o}C)	Lower Heating Value (MJ/kg)
	ASTM D 6751	ASTM D 1298	ASTM D 445	ASTM D 2015
D0	52.1	0.838	2.4	41.3
DHX8	51.6	0.812	2.14	41.95
DHX16	50.7	0.788	2.03	42.8
R0	60.1	0.834	4.47	39.35
RHX8	56.4	0.817	3.09	39.54
RHX16	54.2	0.809	2.67	39.81
C0	57.1	0.886	4.64	38.69
CHX8	54.2	0.871	3.51	38.95
CHX16	51.5	0.852	2.79	39.16
n-hexane	44.8	0.65	0.51	---

Engine experiments were carried out in 6 different rpm at constant engine operating temperature, ensuring stable working conditions. Improving of fuel properties was intended with n-hexane additive in biodiesels. The experimental setup is shown in Fig.1. The technical properties of the test engine were given in Table 2.

Bosch-BEA 350 model exhaust emission device and Bosch brand RTM430 model smoke measurement kits were used. It measures NOX, CO2, CO, HC, emissions and smoke darkness, the rate of exhaust gas to volumetric flow rate as the measurement system of CP forms from CP sensor, amplifier, encoder data acquisition card. It sensitively filters and provides the conversion of the voltage produced by the pressure sensor depending on the pressure inside the cylinder. Table 3 shows the features of cylinder pressure measuring system elements. CP was obtained by considering of pressure inside the cylinder obtained for every 1oCA range up to 720 oCA in each cycle. Table 3. Features of cylinder pressure measuring system elements. Some corrections must be made to the signals before processed. After converting the analog signals of the pressure sensor to digital signals, the pressure data obtained by multiplying the reference pressure value with pressure sensor. In-cylinder pressure values were gained at 1 °CA intervals and converted into digital signals.



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.

Fig. 1. Experimental setup [26]

Table 2. Specifications of test engine

Model	3-LD-510
Number of cylinders	1
Volume of cylinder	510
Diameter-Strok, mm	85x90
Compression ratio	17.5:1
Maximum engine speed,	3300
Maximum engine torque,	32.8
Maximum engine power,	9
Cooling type	Water cooling

Table 3. Features of cylinder pressure measuring system elements

Pressure Sensor	
Brand – Model	Kistler- 6052C
Type	Piezoelektrik
Measuring range, bar	0-250
Operating temperature, °C	-20-350
Amplifier	
Brand – Model	Kistler-5018A
Number of canal	1
Measuring range, pC	2-2200000
Output signal, volt	-10-10
Frekans, kHz	0-200
Operating temperature, °C	0-50
Encoder	
Brand – Model	Kübler-Sendix 5000
Measuring range, rpm	0-12000
Operating temperature, oC	-40-85

$$P_{i+2} = P_i + \frac{2P_i' d\theta}{1!} + \frac{2^2 P_i'' d\theta^2}{2!} + \frac{2^3 P_i''' d\theta^3}{3!} + \frac{2^4 P_i'''' d\theta^4}{4!} + \cdots$$

$$P_{i+1} = P_i + \frac{P_i' d\theta}{1!} + \frac{P_i'' d\theta^2}{2!} + \frac{P_i''' d\theta^3}{3!} + \frac{2^4 P_i'''' d\theta^4}{4!} + \cdots$$

$$P_i = P_i \tag{1}$$

$$P_{i-1} = P_i - \frac{P_i' d\theta}{1!} - \frac{P_i'' d\theta^2}{2!} - \frac{P_i''' d\theta^3}{3!} - \frac{2^4 P_i'''' d\theta^4}{4!} - \cdots$$

$$P_{i-2} = P_i - \frac{2P_i' d\theta}{1!} - \frac{2^2 P_i'' d\theta^2}{2!} - \frac{2^3 P_i''' d\theta^3}{3!} - \frac{2^4 P_i'''' d\theta^4}{4!} - \cdots$$

According to four nodes,1st order derivative of the function is seen in Eq. 2.

$$P_i = \frac{P_{i-2} - 8P_{i-1} + 8P_{i+1} - P_{i+2}}{12 d\theta} \tag{2}$$

3. Results and Discussion

Fig.2 and Fig.3 shows the engine power and torque graph. With the increase of n-hexane ratio in diesel and biodiesels, engine torque and engine power increased in all speeds. The maximum engine torque was obtained in 1400 rpm and there was 0.6% improvement in DHX8 fuel and 1.09% improvement in DHX16 fuel compared to D0 fuel. According to R0 fuel, 4% improvement was obtained as in RHX8 fuel and 5% in RHX16 fuel. It was 1.55% in CHX8 fuel and 3.29% in CHX16 fuel compared to C0 fuel. Adding of additive in biodiesel fuels has better effect than diesel. This is result from that the biodiesel fuel properties worse than diesel fuel. Maximum engine power was obtained in 2800 rpm 8.40, 8.55 and 8.65 kW for D0, DHX8 and DHX16 fuels respectively, 7.17, 7.53 and 7.72 kW for R0, RHX8 and RHX16 fuels respectively, and 7.74, 7.90 and 8.15 kW for C0, CHX8 and CHX16 fuels respectively.

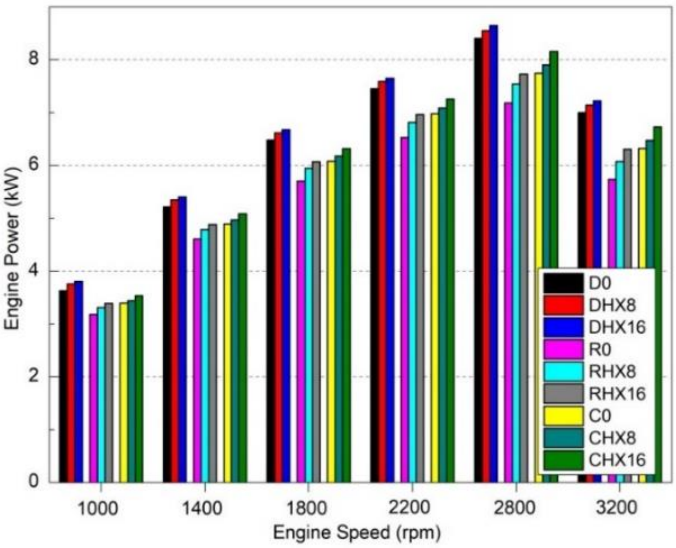


Fig. 2. Engine power graph of test fuels

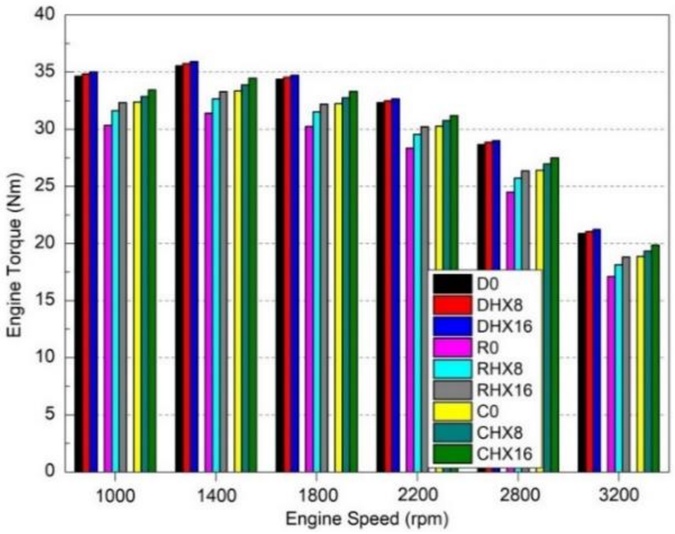


Fig. 3. Engine torque graph of test fuels

The BSFC graph was given in Fig. 4. Those values were 263.92 g/kWh in D0 fuel, 304.97 g/kWh in R0 fuel and 288.61 g/kWh in C0 fuel in 1400 rpm. The maximum decreasing in BSFC was obtained as 1.49% in DHX16 fuel. The 8.81% in RHX16 fuel and 5.55% in CHX16 fuel at 3200 rpm. The density, viscosity and cetane number of the fuels decreased but LHV increased with adding n-hexane additive. The features of the spraying fuel in diesel engines have a big impact in performance. Improvement of density, viscosity, and LHV properties affected the penetration of fuel into the cylinder and allowed better atomization. It can be thought that the result of good fuel atomization and improved combustion quality by added to n-hexane, higher torque and power were obtained in experiments.

Better fuel atomization forms smaller fuel droplets in combustion chamber. It provides better fuel-air mixture. Although fuel injection behaviors depend on fuel system properties and geometry, it was also affected by fuel properties such as lower density and lower viscosity. This is because n-hexane forms better combustion reaction at low temperatures. Keeping the mixture within a certain limit is important for engine power [11-13]. The density, viscosity and LHV of the fuel's effects BSFC. The fuel which has higher LHV ensures better BSFC. Reducing BSFC will have an impact on greenhouse gas emissions, energy security, and price of fossil fuels [14].

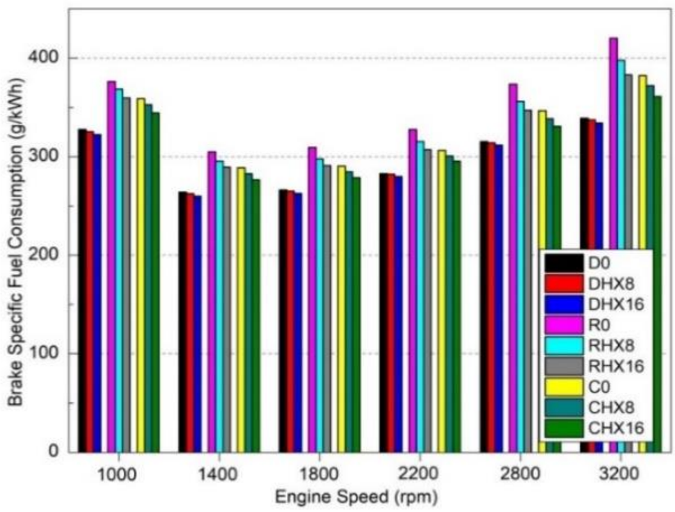


Fig. 4. BSFC graph of test fuels

The cylinder pressure and HRR graphs were given in Fig. 5-7. The viscosity can change the combustion process because of it affects the molecular structure of the fuel and energy content. Since the high viscosity wills forms larger fuel droplets during spraying, the ID increases. Addition of additive causes a decrease in viscosity and density. Combustion will be better since this positively affects to atomization, evaporation and spread in the cylinder [15].

The increase in CP affected the reduction of BSFC and burning time. With the addition of the additive, the viscosity decreased, and the viscosity approached the more ideal point. So, it improved the atomization characteristic and provided better combustion and higher CP. The HRR and ID and are important parameters to investigate of combustion characteristics of diesel engines. Fuels with high cetane number provide shorter ID and better fuel-air mixture. Fuel with low density and viscosity evaporates more quickly and makes shorter ID. The rate of HRR is directly dependent on ID and fuel characteristics [24].

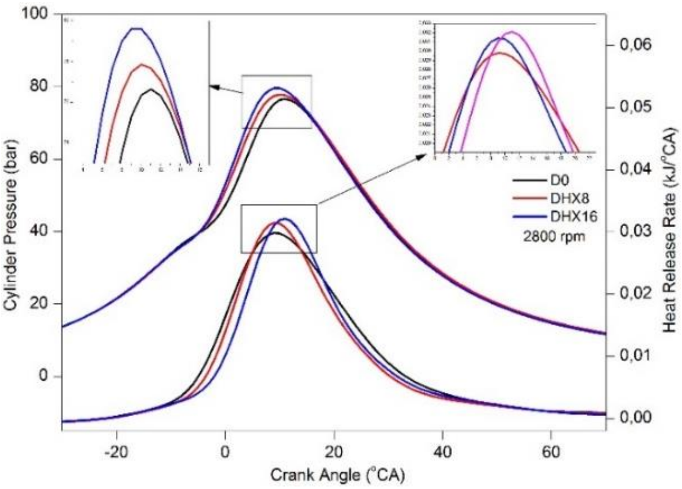


Fig. 5. CP-HRR graph of diesel n-hexane mixture

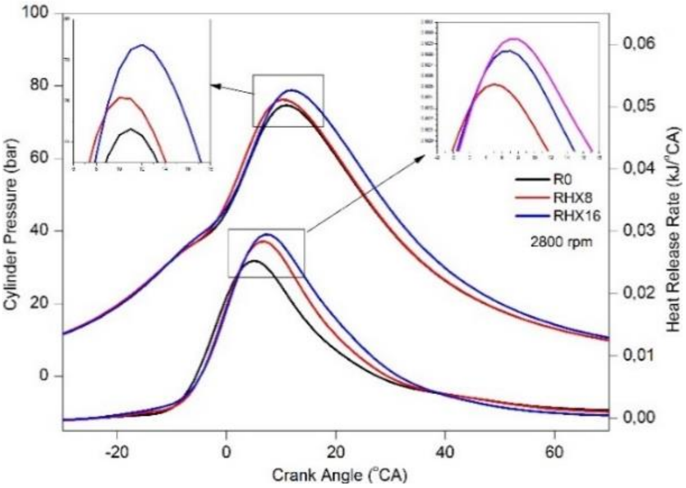


Fig. 6. CP-HRR graph of rapeseed methyl ester n-hexane mixture

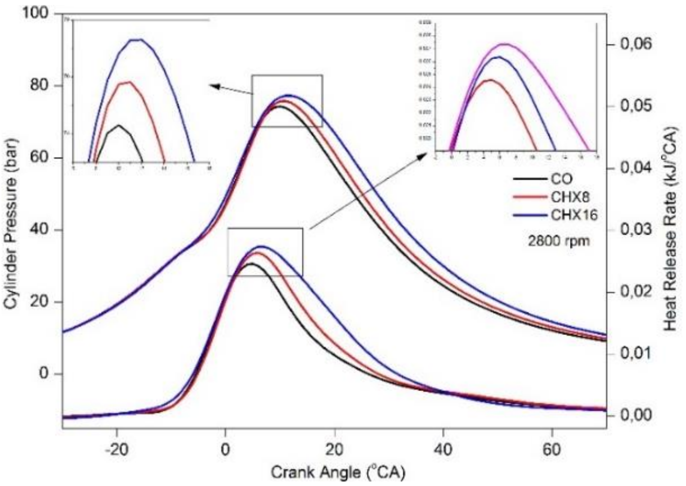


Fig.7. CP-HRR graph of cottonseed methyl ester n-hexane mixture

In previous studies, cetane number, LHV, H/C ratio, etc. showed that fuel properties affect maximum cylinder pressure, HRR and combustion temperatures [16]. The time of ID at 1400 rpm was 14-12 and 13oCA in D0, R0 and C0 fuels, respectively. With the addition of additives, the ID time was shortened because the additives of the fuels strengthened the combustion. ID time for DHX16-RHX16 and CHX16 fuels in test fuels was 11-10 and 11oCA, respectively. With the reducing of viscosity of fuel, better evaporates and penetrates the larger area of the fuel being sprayed. This situation allows to better mix of fuel with the air during combustion. The combustion completes in a shorter time and not overlaps the combustion phase. It is thought that faster burning increased brake thermal efficiency.

Fig.8 and Fig.9 show CO and HC graphs. It is determined that CO and HC emissions of biodiesel are lower than diesel fuel [16]. The maximum reduction was 7.07% in DHX16 fuel compared to D0 fuel, 12.86% in RHX16 fuel compared to R0 fuel, and 12.85% in CHX16 fuel compared to C0 fuel at 2800 rpm. In HC emissions, the maximum reduction was 17.04% in DHX16 fuel compared to D0 fuel, 18.42% in RHX16 fuel according to R0 fuel, and 16.66% in CHX16 fuel according to C0 fuel. NOX emissions are affected fuel properties and engine type, shape of combustion chamber, injection time and type of injection system [16]. Exhaust gas emissions are directly related to the distribution of the fuel spray [25]. Better viscosity and density values of the fuels with additives increased the evaporation speed of fuel spray and provided better combustion quality.

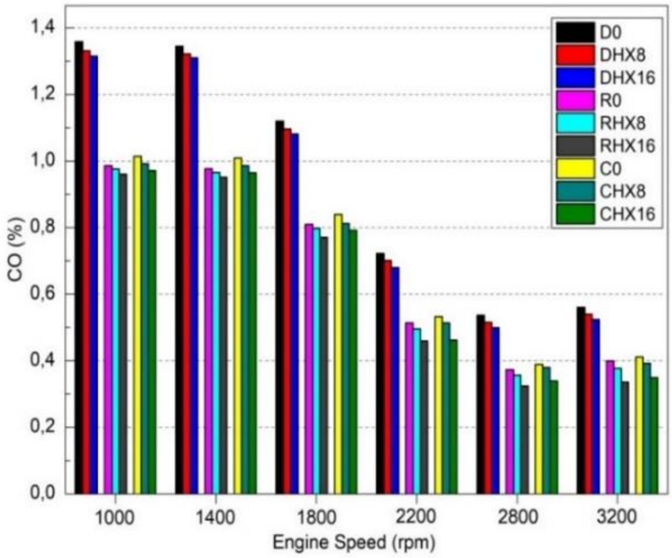


Fig. 8. Graph of CO emission of test fuels

Fig.10 and Fig.11 show NOX and smoke emission graphs. In NOX emissions, compared diesel (D0) fuel, there was 2.12% increase in R0 fuel and 3.76% increase in C0 fuel at 2800 rpm. There are 4.73% increase in DHX16 fuel compared to D0 fuel, 0.98% in RHX16 fuel according to R0 fuel, and 2.01% in CHX16 fuel according to C0 fuel. Addition of additives in fuels increased NOX emissions. The smoke emissions decreased by 22.30% in R0 fuel and by 16.24% in C0 fuel according to diesel (D0) fuel. The additive decreased to smoke emissions by 8.66% in DHX16 fuel compared to D0 fuel, 17.10% in RHX16 fuel compared with R0 fuel, and 9.35% in CHX16 fuel according to C0 fuel. The reason of decrease in smoke emissions in biodiesel fuels compared to diesel fuel is the low sulfur and natural oxygen content in biodiesel content. Besides, this caused an increasing in NOX emissions. Combustion recovery causes high flame temperature [23]. The decreasing of density and viscosity of the fuel positively effects evaporation and atomization. Higher combustion temperature, LHV losses cause increase in NOX emissions. The additive increases the combustion temperature and cause the formation of higher NOX in the cylinder. Smoke is an undesirable product for diesel engines. Lower density and viscosity of the fuel with n-hexane addition, improved atomization and decreased smoke emissions.

4. Conclusion

In this study it was determined that LHV, viscosity, and density values increased while cetane number decreased with n-hexane additive in test fuels. The cetane number is important fuel specification for diesel engines. It was seen in this study, better density and viscosity prevents the adverse effects of the decreasing of cetane number. Since the additive positively affected the fuel atomization characteristics, combustion performance increased. Accordingly, compared to fuels without additives, the engine torque increased in DHX16 - RHX16 and CHX16 fuels by 2.97%-7.67% and 5.29% respectively. BSFC decreased by

1.53%-5.16% and 4.18%, respectively. The pressure and heat diffusion in the cylinder increased due to better combustion with additive. The additive reduces CO and HC emissions, especially in rich fuel areas. When compared to base fuels which have not additive CO emissions decreased 7.07%-12.86%-12.85% respectively in for DHX16, RHX16 and CHX16 fuels. On the other hand, emissions of HC decreased by 17.04%-18.42%-16.66% and smoke emissions decreased by 8.66%-17.10% and 9.35% in DHX16, RHX16 and CHX16 fuels. NOX emissions increased by 4.73%-0.98% and 2.01% respectively. It is understood from the changes in emission values that the additive positively affects the full combustion reactions in the cylinder.

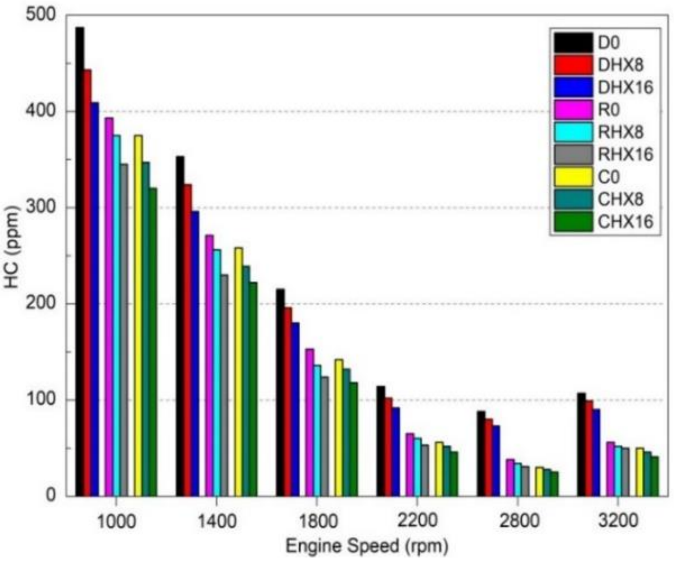


Fig. 9. Graph of HC emission of test fuels

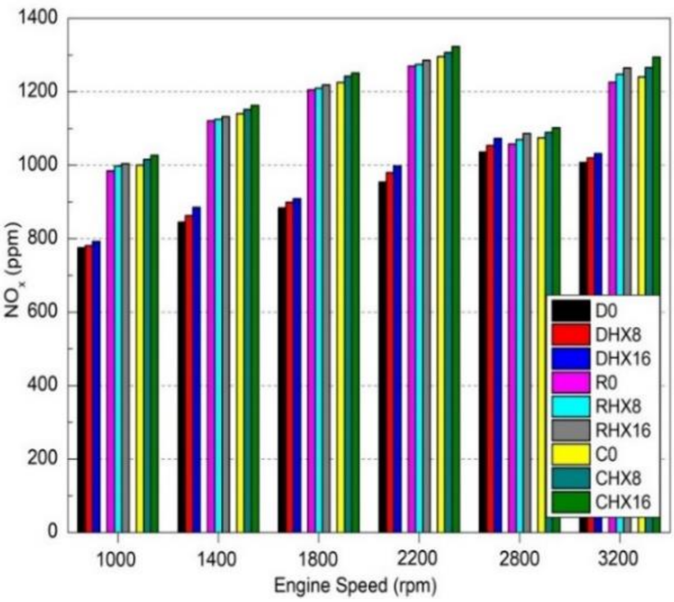


Fig. 10. Graph of NOX emission of test fuels

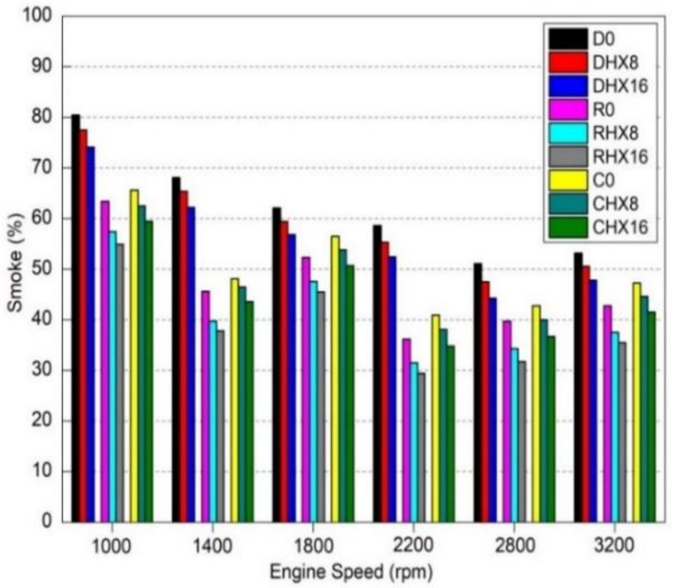


Fig. 11. Graph of Smoke emission of test fuels

Nomenclature

A_{pis}	area of piston top (m^2)
BSFC:	brake specific fuel consumption
BSEC	brake specific energy consumption
HRR	heat release rate
CP	cylinder pressure
LHV	lower heating value
BTE	brake thermal efficiency
ID	ignition delay
CIE	compression ignition engines
CO	carbon monoxide
CO2	carbon dioxide
NOX	nitrogen oxide
HC	unburned hydrocarbon
D0	diesel fuel
DHX8	%92 diesel fuel + %8 n-hexane
DHX16	%84 diesel fuel + %16 n-hexane
R0	Rapeseed methyl ester
RHX8	%92 Rapeseed methyl ester + %8 n-hexane
RHX16	%92 Rapeseed methyl ester + %8 n-hexane
C0	Cottonseed methyl ester
CHX8	%92 Cottonseed methyl ester + %8 n-hexane
CHX16	%92 Cottonseed methyl ester + %8 n-hexane

Conflict of Interest Statement

The authors declare 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 Bayındırlı: Investigation, Writing, Review, Editing, Original draft, Conceptualization.
Recai Kuş: Methodology, Writing – Original draft

References

[1] Rusen SE, Carbas BB, Ulker A. Monthly optimization of a new hybrid renewable energy system considering energy and agricultural efficiency. Int. J. of Energy Applications and Technol. 2016;3:68-71.

[2] Bulut F, Lüy M, Çam E. The effects of incentives on renewable energy resources for home users. Int. J. of Energy Applications and Technol. 2017;4: 94-100.

[3] Du J, Sun W, Guo L, Xiao S, Tan M, Li G, Fan L. Experimental study on fuel economies and emissions of direct-injection premixed combustion engine fueled with gasoline/diesel blends. Energy Convers. Manage. 2015;100:300-309.

[4] Tutak W, Lukacs K, Szwaja S, Bereczky A. Alcohol–diesel fuel combustion in the compression ignition engine. Fuel. 2015;154:196-206.

[5] Karacan S. Biodiesel production using reactive distillation column: Real time model predictive control in Matlab Simulink. Int. J. of Energy Applications and Technol. 2018;5:107-114.

[6] Farobie O, Matsumura Y. Energy analysis for the production of biodiesel in a spiral reactor using supercritical tert-butyl methyl ether (MTBE). Bioresource Technology. 2015;196: 65-71.

[7] Zaharin MSM, Abdullah NR, Najafi G, Sharudin H, Yusaf T. Effects of physicochemical properties of biodiesel fuel blends with alcohol on diesel engine performance and exhaust emissions: A review. Renew. Sustain. Energy Rev. 2017;79:475-493.

[8] Yu YQL, Li Z, Zhang Y, Xu L, Zhou Q, Han D, Lu X. A new methodology for diesel surrogate fuel formulation: Bridging fuel fundamental properties and real engine combustion characteristics. Energy. 2018;148:424-447.

[9] Ibrahim A. An experimental study on using diethyl ether in a diesel engine operated with diesel-biodiesel fuel blend. Eng. Sci. Technol. Int. J. 2018;21:1024-1033.

[10] Çelik,M. Combustion performance and exhaust emission characteristics of organic based manganese addition to cottonseed methyl ester methyl ester. Applied Thermal Engineering. 2016;108:1178-1189.

[11] Yaliwal VS, Banapurmath NR, Revenakar S, Tewari PG. Effect of mixing chamber or carburetor type on the performance of diesel engine operated on biodiesel and producer gas induction. Int. J. of Automotive Engineering and Technol. 2016;5(2):25-37.

[12] Hazar H, Uyar M, Aydın H, Şap E. The Effects of Apricots Seed Oil Biodiesel with Some Additives on Performance and Emissions of a Diesel Engine. Int. J. of Automotive Engineering and Technol. 2016;5(3):102-114.

[13] Agarwal AK, Somb S, Shukla PC, Goyal H, Longman H. In-nozzle flow and spray characteristics for mineral diesel, Karanja, and Jatropha biodiesels. Applied Energy. 2015;156:138-148.

[14] Ashok B, Nanthagopal K, Mohan A, Johny A, Tamilarasu A. Comparative analysis on the effect of zinc oxide and ethanox as additives with biodiesel in CI engine. Energy. 2017;140:352-364.

[15] Mangus M, Kiani K, Mattson J, Tabakh D, Petka J, Depcik C, Peltier E, Stagg-Williams S. Investigating the compression ignition combustion of multiple biodiesel/ULSD (ultra-low sulfur diesel) blends via common-rail injection. Energy. 2015;89:932-945.

[16] Singh D, Subramanian KA, Bal R, Singh SP, Badola R. Combustion and emission characteristics of a light duty diesel engine fueled with hydro-processed renewable diesel. Energy. 2018;154:498-507.

[17] Kaimal VK, Vijayabalan P. A detailed study of combustion characteristics of a DI diesel engine using waste plastic oil and its blends. Energy Convers. Manage. 2015;**105:**951-956.

[18] Yesilyurt MK, Aydın M, Yılbası Z, Arslan M. Investigation on the structural effects of the addition of alcohols having various chain lengths into the vegetable oil-biodiesel-diesel fuel blends: An attempt for improving the performance, combustion, and exhaust emission characteristics of a compression ignition engine. Fuel. 2020;269:117455.

[19] Ning L, Duan Q, Chen Z, Kou H, Liu B, Yang B, Zeng K. A comparative study on the combustion and emissions of a non-road common rail diesel engine fueled with primary alcohol fuels (methanol, ethanol, and n-butanol)/diesel dual fuel. Fuel. 2020;266:117034.

[20] lkelawy M, Kabeel AE, El Shenawy EA, Panchal H, Elbanna A, Bastawissi HA, Sadasivuni KK. Experimental investigation on the influences of acetone organic compound additives into the diesel/biodiesel mixture in CI engine. Sustain. Energy Technol. and Assessments. 2020;37:100614.

[21] Ibrahim A. 2018. An experimental study on using diethyl ether in a diesel engine operated with diesel-biodiesel fuel blend. Engineering Science and Technology, an International Journal (JESTECH), 2018.;21:1024–1033.

[22] Murray R, Wyse-Mason R. Investigation of methanol-biodiesel-coconut oil ternary blends as an alternative fuel for CI engines. Engineering Science and Technology, an International Journal (JESTECH). 2018;21:1056–1066.

[23] Öztürk E, Can Ö, Usta N, Yücesu HS. Effects of retarded fuel injection timing on combustion and emissions of a diesel engine fueled with canola biodiesel. Engineering Science and Technology, an International Journal. 2020;23(6): 1466-1475.

[24] Oo CW, Shioji M, Nakao S, Dung NN, Reksowardojo I, Roces SA, Dugos NP. Ignition and combustion characteristics of various biodiesel fuels (BDFs). Fuel. 2015;158:279-287.

[25] Rajak U, Verma TN. Influence of combustion and emission characteristics on a compression ignition engine from a different generation of biodiesel. Engineering Science and Technology, an International Journal (JESTECH). 2020;23:10–20.

[26] Çelik M, Bayındırlı C. Enhancement performance and exhaust emissions of rapeseed methyl ester by using n-hexadecane and n-hexane fuel additives. Energy. 2020;117643:1-12.