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Original Research Article

Effects on Performance, Emission and Combustion Parameters of Addition Biodiesel and Bioethanol into Diesel Fuel

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Abstract

In this study, safflower based biodiesel produced in the pilot plant were blended with certain amounts of diesel fuel and bioethanol from sugar beet. Diesel fuel and the blends were tested in a direct injection diesel engine and engine performance, combustion and exhaust emission characteristics were investigated. According to test results, the brake specific fuel consumptions of biodiesel blend were about 8.51% higher than diesel fuel. Bioethanol is increased brake specific fuel consumptions values up to 26.77%. The maximum cylinder gas pressure of biodiesel blend was about 0.46% higher than that of diesel fuel on average. This value was decreased about 1.75% with using of bioethanol. The exhaust emission results showed that biodiesel blend decreased carbon dioxide emissions and smoke opacity, while it increased nitrogen oxide emissions and exhaust gas temperature. Nitrogen oxide emissions, smoke opacity and exhaust gas temperature values were decreased with adding bioethanol, while it increased carbon dioxide emissions.

Keywords: Safflower biodiesel, Bioethanol, Diesel engine, Combustion analysis, Exhaust emissions.

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1. Introduction

Increase on energy need of the world, decrease of fossil fuel reserves and increasing air pollution direct the researches to search for new energy resources. It is also very important that alternative energy resources that are being searched are renewable. Sun, wind, geothermal, nuclear, hydraulic, wave, hydrogen and biomass technologies are shown as new and renewable energy resources. Energy resources obtained with biomass technology are generally named as biofuel. Biofuels are the main alternative energy resources that can be replaced with petroleum fuels.

Generally modern energy forms of biomass can be grouped as solid (tree, pellet etc.), liquid (ethanol, biodiesel etc.) and gas (biogas, hydrogen etc.) [1]. Nowadays, biodiesel and ethanol which are among liquid energy forms obtained with biomass technology are the most commonly used renewable energy resources. These energy resources are used in road transportation in particular and in many areas such as electric production, heating and agricultural production.

Biodiesel is a fuel that can be used in CI engines without requiring important modification and it can use mixing to diesel fuel or as pure. It is obtained from renewable resources like animal and vegetable fat. It is known that they give off less carbon monoxide (CO), hydrocarbon (HC) and smoke emission compared to diesel fuel.

Ethanol or bioethanol is commonly used in SI engines. Bioethanol can be obtained from many different nutritional sources such as sugar cane, sugar beet, corn, barley, hemp, potato, cassava, molasses, wheat, other biosolids and various cellulose wastes [2].

The USA in particular and many important EU countries and Brazil make important investments on biofuel usage, impose legal obligations and provide opportunities to encourage. There are many researches related to usage of biodiesel and bioethanol in internal combustion engine. According to these studies, researchers such as Barabas et all. [3], Çelikten [4], Yılmaz [5], Shahir et al. [6] and Sastry et al. [7] presented that brake specific fuel consumption (BSFC) values increased with using of biodiesel and ethanol due to lower heating value (LHV) of both fuels are lower than that of diesel fuel. According to Chauhan et al. [8], Parekh and Goswami [9], Prasad et al. [10], Mofijur et al. [11], Huang et al. [12], Labeckas and Slavinskas [13], brake thermal efficiency (BTE) values of biodiesel and ethanol decreased due to same cause with that of BSFC. However, Dhar et al. [14], Swaminathan and Sarangan [15] and Tomic et al. [16] have revealed that addition of low rate biodiesel increased BTE due to reduction of injection pumping losses because of biodiesel increases density and viscosity. Rounce et al. [17], Su et al. [18], Lesnik et al. [19], Rakopoulos et al. [20], Lapuerta et al. [21] and Anbarasu et al. [22] presented both biofuels increased maximum cylinder pressure (MCP) due to boost the combustion speed of oxygen content of biofuels. According to study results of Chen et al. [23], Qi et al. [24], Zhu et al. [25] and Imtenan et al. [26], maximum heat release rate (MHRR) also increased by oxygen content of biodiesel and ethanol. İlkılıç et al. [27], Ong et al. [28] and He et al. [29] presented that exhaust gas temperature (EGT) increased with using biodiesel due to early starting of combustion by shortening ignition delay of biodiesel. But, it decreased with using bioethanol due to the reason that latent evaporation heat of ethanol is higher than diesel fuel and biodiesel. Sugözü [30], Fattah et al. [31], Lesnik et al. [19], Mofijur et al. [11], Kim and Choi [32], Lei et al. [33], Dhar et al. [14], Jagadish et al. [34], Yılmaz et al. [35], Qi et al. [24] and Ong et al. [28] presented that biodiesel increased NO_X emission due to its higher EGT and oxygen content. Ethanol decreased by its lower EGT. Both biodiesel and ethanol decreased soot emission for they more cleanly burned. However, biodiesel was increased CO emission while ethanol decreased it.

According to the literature review, adding 20% biodiesel to diesel fuel improves lubricity property of the fuel, decrease engine emission but does not decrease engine performance parameters much. In this study, biofuels, which is obtained from safflower and sugar beet grown locally in Turkey, were used. Safflower is a plant that does not need water much agriculturally and can be grown easily. Diesel fuel was mixed with 15% biodiesel in volume and 5% and 10% bioethanol were added to this mixture to minimalize biodiesel's negative properties such as high viscosity, low combustion velocity, bad cold flow.

According to these researches, the usability of biodiesel in diesel engines has been proved. Biodiesel can be used in today's engines, yet mixed with diesel fuel. However, there are a number of reasons that negatively impact the usability of biodiesel. The most important of these reasons is that biodiesel has bad cold flow characteristics compared to an engine fuel. Furthermore, it releases higher NO_X emission than diesel fuel to atmosphere. In this study, which aims to demonstrate of its usability the negatives of biodiesel by minimizing, the bioethanol at certain rates added into biodiesel-diesel fuel blends. Biodiesel and bioethanol mixed in diesel fuel are produced from obtained safflower oil and sugar beets from entirely regional and local sources. These fuel mixtures were used a diesel engine and, were examined the effects on performance, combustion and emission parameters. The originality of this study is to be renewable of biofuels using in tests, and they produced from entirely regional feedstock materials.

2. Material and Method

2.1. Test fuels

Biodiesel used in the tests was produced from Remzibey type safflower seed oil with transesterification method in Biodiesel Production Facilities of Selçuk University. Bioethanol was produced from sugar beet in Çumra Integrates Facilities of Konya Sugar Factory. While mixing test fuels, diesel fuel was added to biodiesel, bioethanol was injected to the mixture to avoid the loss due to volatility of alcohol and mixed with magnetic stirrer at constant temperature. No phase decomposition was observed about 6 week period. Fuel properties determined analysis methods as EN ISO 121 (density), EN ISO 310 (viscosity), ASTM D 24 (LHV) and EN ISO 516 (cetane number).

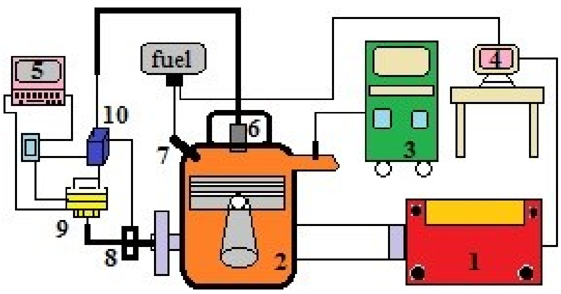
Test fuels were coded as DF (100% diesel fuel), B15 (85% diesel fuel + 15% biodiesel), BE5 (80% diesel fuel + 15% biodiesel + 5% bioethanol) and BE10 (75% diesel fuel + 15% biodiesel + 10% bioethanol). Physical and chemical properties of test fuels were tested in the Energy Institute of the Marmara Research Center which is accredited by The Scientific and Technological Research Council of Turkey (TUBITAK), and analysis results were presented in Table 1.

Table 1. Some fuel properties of test fuels.

Property	DF	BD15	BE5	BE10
Density, at 15°C (kg/m^3)	834.5	841.7	838.6	836.3
Viscosity, at 40°C (mm^2/s)	2.794	2.957	2.841	2.834
LHV (Mj/kg)	43.14	42.31	41.57	40.84
Cetane number	55.2	55.6	53.8	51.2

2.2. Testing apparatus and testing equipment

During the tests, direct injection and single-cylinder diesel engine whose features were given in Table 2 were used. Specification of hydraulic dynamometer used for adjusting engine load, specifications of pressure sensor, encoder and amplifier used for combustion analysis, specification of emission analyzer used for exhaust gas analysis, properties of load-cell used for engine torque and fuel consumption were given in Table 3. Equipment used during the tests were shown in Figure 1 schematically.



1: Hydraulic dynamometer 2: Test engine 3: Gas analyzer
4: Engine controller 5: Computer
6: Pressure sensor 7: Injector 8: Encoder 9: Data logger
10: Amplifier
Fig. 1. Schematic of the experimental setup

Table 2. The specification of test engine.

Model	Antor 3LD510
Engine type	Four stroke Direct injection
Cylinder number	1
Total cylinder volume (cm^3)	510
Diameter x Stroke (mm x mm)	85 x 90
Compression rate	17.5:1
Max. engine speed (rpm)	3300
Max. engine torque (Nm)	32.8
Max. engine power (kW)	9
Injector pressure (bar)	190

Table 3. Features of measure equipments.

Hydraulic dynamometer		
Mark – Model	Range of speed (rpm)	Range of torque (Nm)
Net fren-NF150	0-6500	0-450
Load cell for torque		
Mark – Model	Range of weight (kg)	
CAS - SBA 200L	0-200	
Load cell for fuel consumption		
Mark – Model	Range of weight (kg)	
CAS - BCL-1L	0 – 3	
Pressure sensor (Kistler – 6052C)		
Type	Range of measure (bar)	Working temp. (°C)
Piezoelectric	0 – 250	-20 – 350
Amplifier (Kistler – 5018A)		
Channel number / Working temp. (°C)	Range of measure (pC)	Output signal (v) / Frequency (kHz)
1 / 0 – 50	2 – 2200000	-10 – 10 / 0 - 200
Encoder		
Mark – Model	Working temp. (°C)	Range of measure (rpm)
Kübler – Sendix 5000	-40 – 85	0 – 12000
Gas analyzer		
CO (v/v)	NO (ppm)	Smoke opacity (%)
0 – 10	0 – 5000	0 – 100

2.3. Testing Method

Tests were performed in Automotive Laboratory of Aksaray University. Tests were carried out by keeping the speed fixed on each 200 rpm engine speed between 1000 – 3000 engine speeds by changing dynamometer load while engine is on full throttle opening. Before measurements, engine was brought in working temperature. Cylinder pressure values were recorded during at least 50 cycles at 1° crank angle and their average was calculated. CO and NO emission values were converted to the units of g/kWh as the study of Pilusa et al. [36].

3. Results

Test results were presented as thermal efficiency and BSFC values as engine performance parameters; cylinder pressure and heat release rate values as combustion analysis; exhaust gas temperature, CO, NO and smoke opacity as exhaust emission parameters. Uncertainty analysis of test results was shown in Table 4.

Table 4. Accuracies of the measurements and the uncertainties in the calculated results.

Measured Data	Accuracy	Uncertainty
Fuel weight (g)	±0.01	-
Engine speed (rpm)	±1%	-
Load (g)	±1	-
Engine torque (Nm)	-	±0.38%
Engine power (kW)	-	±0.61%
Fuel consumption (g/s)	-	±0.44%
BSFC (g/kWh)	-	±0.52
BTE (%)		±0.54
CO (v/v)	±0.001	-
NO (ppm)	±1	-
Smoke opacity (%)	±0.01	-
Tex (°C)	±2	-

3.1. Engine performance parameters

Figure 2 shows BSFC and BTE values for each test fuel based on engine speed. According to the results which were obtained, biodiesel increased BSFC values by average of 8.51%, 5% bioethanol addition increased them by average of 16.51%, 10% bioethanol addition increased them by average of 26.77%. When BTE was examined, B15 fuel decreased BTE value by average of 6.31%. BE5 and BE10 decreased BTE values by average of 11.22% and 16.91% respectively compared to DF.

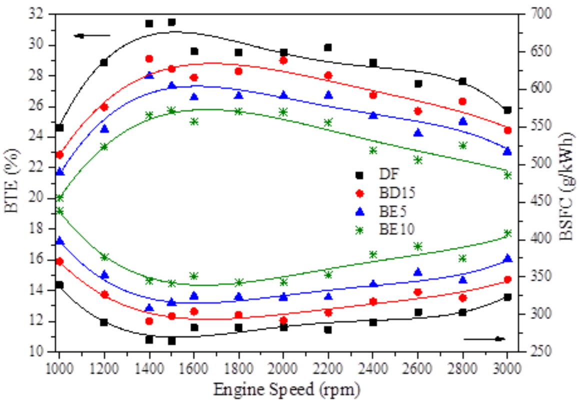


Fig. 2. BSFC and BTE values at different speeds

One of the reasons why biodiesel usage effects BSFC and BTE parameters negatively can be explained as high density and viscosity values of biodiesel effect injection characteristics negatively. BSFC values of B15 fuel are higher compared to DF because that situation decreases combustion quality and efficiency. Because both biodiesel and bioethanol have lower LHV value compared to DF, this caused more fuel consumption to have same engine power with DF and affected engine performance negatively.

3.2. Combustion Analysis

Figure 3 (a (1400 rpm) and b (2800 rpm)) show cylinder pressure at 1400 rpm and 2800 rpm engine speed at which maximum engine torque and maximum engine power were obtained and heat release rate values. MCP of B15 fuel at both engine speed was higher than DF. Furthermore, bioethanol addition increased MCP value more. Oxygen found in biodiesel and bioethanol increased combustion speed momentarily compared to DF and this increased MCP value. Besides, cetane number of biodiesel was just a little higher than DF and it decreased ignition delay time of B15 slightly. Thus, it caused increase of MCP. Bioethanol extends ignition delay because of its low cetane number and it increases quantity of fuel injected to combustion chamber. That situation caused increase of MCP value.
Biodiesel in the mixture makes combustion difficult because it increases heat of vaporization. Thus, more fuel accumulates in cylinder during the time passing till combustion start and instantly high speed combustion starts because of oxygen content. That's why, MHRR value of B15 fuel is higher than DF's. Cetane number of bioethanol is low and it increases ignition delay. These cause increase of fuel quantity which accumulated during this time. Furthermore, oxygen content of mixed fuels increases with bioethanol addition. Thus, accumulated fuel combusts instantly and combustion speed increases by the effect of oxygen. That situation can be explained as the reason why bioethanol increases MHRR values at high engine speeds. However, it is seen that at 1400 rpm engine speed, bioethanol decreases MHRR value. That situation can be explained as bioethanol creates more homogeneous mixture in the cylinder with its high volatility characteristic and it causes combustion starts earlier.

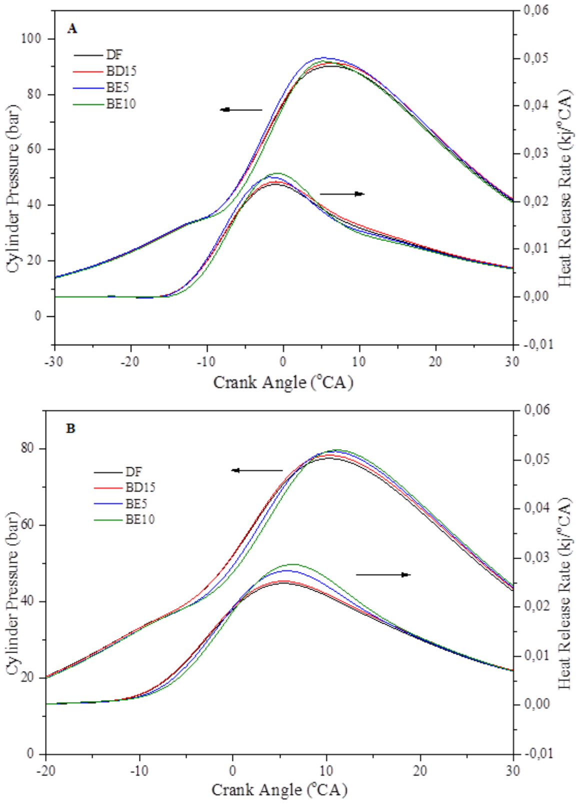


Fig.3. Combustion analysis at 1400 rpm and 2800 rpm

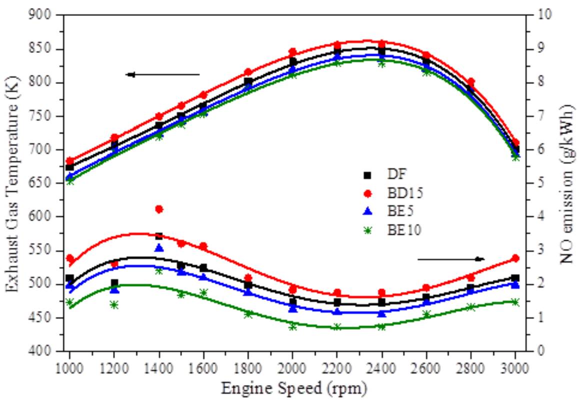


Fig. 4. EGT and NO emission at different speeds.

3.3. Exhaust Emissions

Figure 4 shows EGT and NO emission values for each test fuel based on engine speed. The oxygen content of biodiesel was improved combustion. Furthermore, it is thought that exhaust gas heat increases because ignition delay decreases a little with biodiesel usage and start of combustion earlier shortens combustion duration. Because bioethanol's

latent heat of vaporization is high, it takes more ambient temperature to vaporize and that causes reduction of EGT.
NO emission is directly proportionate to EGT. N and O atoms react in high temperatures. For this reason, while NO emission value of B15 fuel increased by average of 22.26%, NO emission values of BE5 and BE10 fuels decreased by average of 12.14% and 37.44% respectively.
Figure 5 shows CO emission and opacity values for each test fuel based on engine speed. Biodiesel contains oxygen and that can be explained by the conversion of C atoms to CO_2 gas by finding enough O atoms. Furthermore, stoichiometry air/fuel ratio of biodiesel is lower than DF, it needs less oxygen during combustion and improves combustion efficiency and these decrease CO emissions of B15 fuel by average of 41.54%. That situation can be explained as bioethanol decreases cetane number and it makes combustion worse and combustion speed increases; thus, C and O atoms do not have enough time to react.

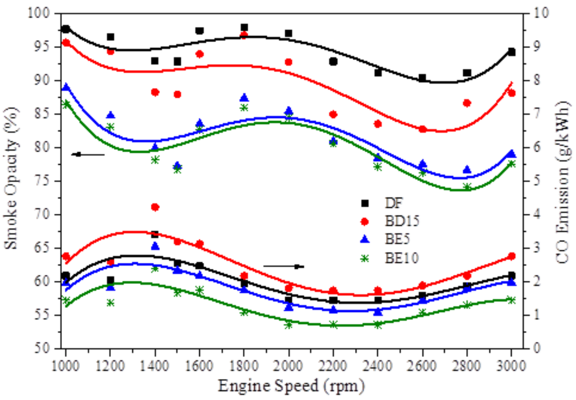


Fig. 5. Smoke opacity and CO emission at different speeds.

Moreover, bioethanol's auto evaporation feature is better. That enables bioethanol to mix with the air in the cylinder earlier and this prevents full combustion. CO emission values of BE5 increased by average of 26.51% compared to B15 fuel but they decreased by average of 38.92% compared to DF. CO emission values of BE10 increased by average of 1.92 times more compared to B15 and they increased by average of 50.32% compared to DF.

Since both biodiesel and bioethanol combust cleaner thanks to the oxygen they contain, they decreased opacity. B15, BE5 and BE10 fuels decreased opacity values by average of 5.04%, 13.5% and 14.99% respectively compared to DF.

4. Conclusion

As a result of tests, engine performance, in-cylinder combustion analysis and exhaust emission values of biodiesel and bioethanol usage were examined and results were presented below;

1. Combustion energy decreased because especially biodiesel and bioethanol had lower heating value compared to DF, biodiesel affected injection characteristic negatively because its viscosity and density were high, bioethanol made combustion characteristics worse because it decreased cetane number and all these affected engine performance values of both biodiesel and bioethanol negatively.
2. It is seen that maximum pressure and heat release ratio values of biodiesel and bioethanol usage increased in general. While it is expected that especially when cylinder pressure values increased, engine performance values would increase, it is determined that performance values decreased due to biofuel usage. That situation can be explained as because biofuel mixtures contain oxygen, during combustion duration, flame burns out before it grows; in other words, caliber of flame is small and pressure force on piston dome has an effect on miner piston surface.
3. Biodiesel contains a little oxygen and this provides combustion possibility which is close to full combustion. That's because it is estimated that increase of exhaust heat increased NO emission values though it decreased CO and opacity values. It is thought that oxygen existing at high level in bioethanol and high latent heat vaporization values increased CO emission values by affecting combustion negatively but it decreased opacity because it contains a little C atom and it

decreased NO emissions because it decreased exhaust gas heat.
4. Especially biodiesel shows very similar fuel properties to diesel fuel.

Consequently, this study reveals that biofuel usage is possible in diesel engines without requiring a huge modification in engine. Furthermore, it is also possible to use biofuels in diesel engines efficiently by optimizing parameters such as structure of the injector and injection pressure, combustion chamber form, injection advance.

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