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Original Research Article

The effects of walnut biodiesel- eurodiesel fuel mixtures on the performance and emissions of a diesel engine with common rail fuel system and their combustion characteristics

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ABSTRACT

This study is intended to investigate the effects of biodiesel and eurodiesel mixtures, obtained from walnut oil by transesterification method, on engine performance in a four-stroke, four-cylinder, water-cooled with common rail fuel system. 7% biodiesel - 93% eurodiesel (B7), 10% biodiesel - 90% eurodiesel (B10) mixtures were prepared with the fuels obtained from the walnut oil by transesterification method. Later, B7, B10 and eurodiesel (B0) were used as a fuel in diesel engine. In the tests, the engine compression rates of the eurodiesel fuel and biodiesel mixtures were close to each other in all engine rpms. Looking at the average values in the results obtained, it is seen that the highest engine torque value is measured in the range of 2000 - 2500 rpm. Again, in eurodiesel use, the highest engine torque values were measured as 185 Nm. When B7 and B10 fuels were used at the same engine rpm, the engine torque was measured as 165 Nm. As the engine speed increased, it was observed that B7 fuel consumption values were the lowest and the eurodiesel values were the highest. In case of using biodiesel mixtures, it was observed that fuel consumption increased slightly checked to eurodiesel fuel.

When the exhaust emission values were examined, it was seen that the CO emission value was 28% lower than Eurodiesel in B10 fuel, the highest value in CO2 emission was in B10 fuel, HC emission was in Eurodiesel fuel with an increase rate of more than 50% and the highest NOx value was in B10 fuel.

In all cycles, the highest cylinder pressure values were obtained in eurodiesel fuel mixture. Maximum in-cylinder pressure value was obtained as 72 bar in Eurodiesel fuel at 2500 rpm. In the same cycle, 71 and 68 bar in-cylinder pressure values were obtained for B10 and B7 fuels. At 4000 rpm, in-cylinder pressure values were obtained as 80, 77 and 75 bar, respectively, for diesel fuel, B10 and B7 fuel mixtures.

Keywords: Biodiesel, walnut oil, eurodiesel, common rail, emissions

1. Introduction

The consumption of fossil fuels causes the release of some substances harmful to the environment and human health [1-3]. The spread of these substances into the environment causes not only damages in a certain region such as water and air pollution, but also climatic changes that have a global impact, and most importantly, global warming [4-7]. For this reason, some restrictions have been imposed on the states with agreements involving the whole world and efforts have been made to reduce emissions [8]. As an example, countries that signed the Kyoto Protocol, which came into force on 11 December 1997, stated in 2012 that they would reduce their emission values below the 1990 values [9].

Biodiesel is a type of fuel produced from vegetable or animal oils that can work on all unmodified diesel engines. Biodiesel can be produced from plants such as soybean seed, sunflower, rape seed, coconut and hemp. Biodiesel is also produced from used oils in restaurants, dining halls or homes [8, 10-14]. In addition, biodiesel has a good lubricating property compared to diesel fuel, high cetane number for good ignition, high flash point and low sulfur content [15]. The disadvantages are that it causes some increase in NOx emission with very high viscosity, high pour point, low calorific value [16,17].

Walnut, one of the oldest types of nuts cultivated in the world, is grown in many provinces of Turkey. In this context, our country is one of the most important countries in the world in walnut production. According to 2017 data, Turkey produced 210 thousand tons of walnut. 5.20% of world walnut production is carried out in Turkey [18].

Walnut is a versatile plant that can grow naturally in our country, where fruit, as well as timber, leaf and green shells can be evaluated. Turkey is one of the countries of walnut plant [19]. It is reported that walnut tree presence and production in Anatolia dates back at least 3000 years and even moved to other growing areas in the world. Walnut trees are considered to be great in many regions of Turkey and festivals are held in its name. Walnut is a long-lasting plant and can be grown in every region of our country. Unlike other types of fruits, the ability to produce fruit without vaccination is the main reason that walnut is a widely grown fruit. In addition, the value of timber has also been a factor in the widespread nature of walnut cultivation in Anatolia [18-20].

Walnut cultivation is easily becoming widespread, as the climate and soil requirements of the walnut vary between wide borders. With the increase in the interest of the private sector in cultivation and the increase in the number of walnut trees that have given fruit in recent years, this plant gains more importance in our country. The development of the alternative medicine sector and the emergence of the positive effects of walnuts on health in this context and the green shells of walnuts are a versatile plant that is used in the paint industry, the fruit in the food and furniture sector, and the oil in the cosmetics sector. Providing state incentives for the establishment of closed gardens in the cultivation of walnuts and making efforts to increase its exports have increased the interest in this plant in our country [18]. For these reasons, it has become important to investigate the production of biodiesel from walnut oil and its effects on diesel engines.

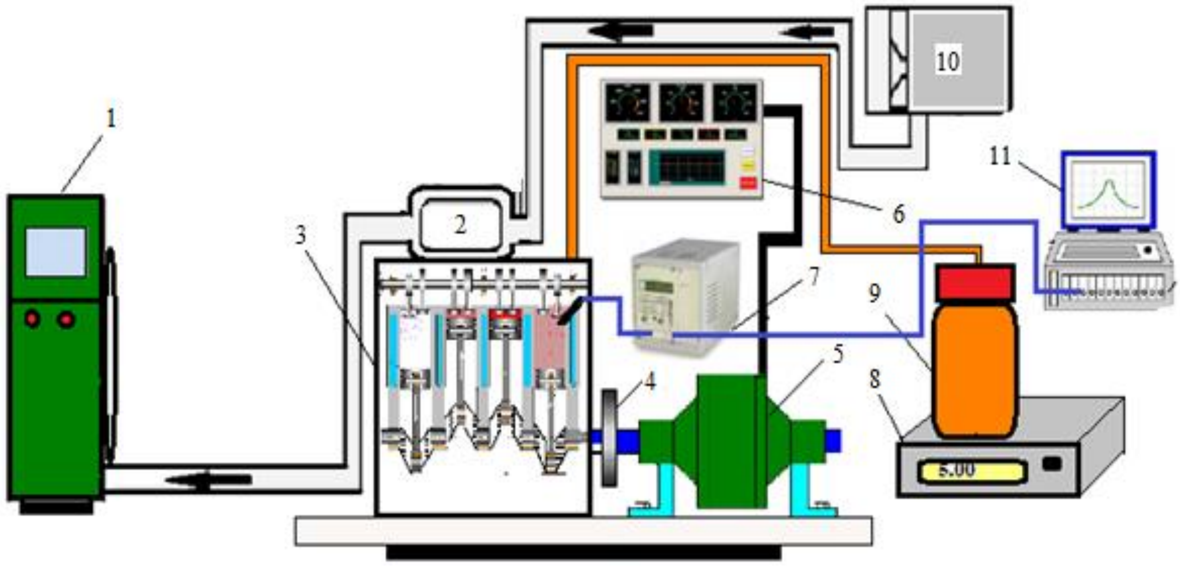
Studies on biodiesel mixtures in engines with common rail fuel system are quite new. The number of studies on walnut biodiesel is very low. In this study, it is aimed to investigate the effects of biodiesel and eurodiesel mixtures on engine performance in a four-stroke, four-cylinder, water-cooled engine accompanied by common rail fuel system. The results were compared and evaluated with each other.

2. Material and Method

The biodiesel fuel used in this research was made from walnut oil using transesterification method. Transesterification is the process by which a triglyceride molecule reacts in the presence of an alcohol and catalyst to produce glycerine and fatty acid alkyl esters. The physical properties of walnut biodiesel and eurodiesel are shown in table 1. When the fuel properties of the walnut biodiesel were obtained from the transesterification process, compared to TS EN 14214 and ASTM standards, the density, viscosity, water content, copper strip corrosion were within the limit values in biodiesel fuel. CFPN (Filter Plugging Point in Cold) could not maintain the limit value for the winter season in blended fuels. Its calorific value was 14.52% lower than eurodisiel. Two different mixtures are discussed in the volumetric mixture. Mixture ratios have been chosen depending on the developments in today's EU, biodiesel standards in the world and the effects of mixtures on performance and emissions [21]. These are, 100% Eurodiesel, 7% Biodiesel + 93% Eurodiesel, 10 % Biodiesel + 90% Eurodiesel.

Table 1. Physical properties of walnut biodiesel and eurodiese

Specifications	Walnut Biodiesel	Eurodiesel
Density (gr/m^3)	0,893	0,827
Viscosity (mm^2/s)	5,23	2,82
CFPN (˚C)	-3	-20
Calorie Value (MJ/kg)	40,6	47,5
Water Content (mg/kg)	166,68	8,8
PH	5,5	6
Copper Rod Corrosion	1a	1a



1. Emission Device
2. Turbo charged
3. Test engine
4. Clutching
5. Hydraulic Dynamometer
6. Control Board
7. Charging Amplifier
8. Precision Scales
9. Fuel Tank
10. Orifice Plate
11. AVL In-cylinder pressure gauge

Figure 1. Test Set up

Table 2. Technical characteristics of the engine used in the study

Engine	1.9 MultiJet diesel
Number of cylinders and their placement	4, single row, transverse ahead
Cylinder volume (cc)	1910
Compression ratio	18.5 : 1
Maximum Engine power kW - rpm	77 - 4000
Maximum moment Nm - rpm	200 - 1750
Fuel system	Electronically controlled Common Rail type MultiJet direct injection, turbo and intercooler
Ignition	compressional
Diameter x Stroke (mm)	82 x 90.4

Table 3. Technical characteristics of the engine dynamometer

Model	BT-190 FR
Maximum Engine power	100 kW
Maximum speed	6000 rpm
Maximum moment	750 Nm

With these mixtures, the tests were carried out with common rail injection system on engine. The test setup used in these tests can be seen in Figure 1. Test engine is a 4 cylinder, turbocharged and intercooler diesel engine with common rail type fuel injection system. The technical properties of engine are given in table 2. Technical characteristics of the engine dynamometer device used in this study can be seen in table 3.

Experiments were carried out at full throttle at different engine speeds. Previously from operation the tests, engine was warmed up to operating heat.

3. Result and Discussion

Figure 2 shows the changes of engine power of eurodiesel fuel and biodiesel mixture fuels depending on engine rpm used in diesel engines. Engine power values characteristically increase in the use of eurodiesel and biodiesel fuel mixtures due to the increase in engine speed. The highest engine power values in entire fuels were achieved in the range of 2000-3000 rpm. In mostly, engine power amount in eurodiesel use at all speeds of the engine were high.

The engine power of biodiesel fuel mixtures were found to be approximately 10% lower than the eurodiesel values. When similar studies are examined, the combustion rate slows down due to the low lower heating value of biodiesel. In addition, kinematic viscosity and the high density of biodiesel and its blends reduce the combustion efficiency and slows down the fuel-air mixture speed. Since the oxygen content of biodiesel fuels improves combustion characteristics, it can be showed that it keeps engine performance characteristics at a reasonable level according to its eurodiesel fuel. The main reason for the difference in engine power values of mixed fuels, especially after 2500 rpm, is the lower calorific value of biodiesel compared to euroldiesel fuel. It is seen that the values are compatible with the studies by Kan et al., Nautiyal et al. and Mairizal et al. [8, 12, 22].

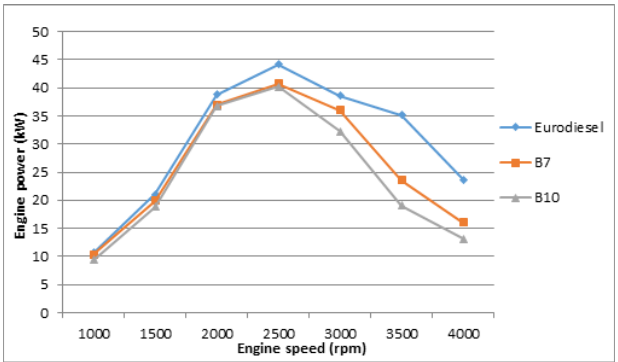


Figure 2. Changes of engine power values according to engine speed

Figure 3 shows the change of engine torque values according to engine rpm. Looking at the average values, it is seen that the highest engine torque value is measured in the range of 2000 - 2500 rpm. When the graph is inspected, it is seen that the highest engine torque values are measured as 185 Nm in eurodiesel use.

When using B7 and B10 fuels at the same engine rpm, engine torque value was measured as 165 Nm. As the engine speed increased, it was observed that the values in B7 fuel use were lowest and the eurodiesel values were highest. Because of to the low lower heating value of the biodiesel, low values occur in torque as well as in engine power. The results obtained were similar to other studies [22-26].

When the obtained results are compared with the previous studies using different biodiesel, though there are deviations, it is observed that these deviations are due to the experimental conditions, engine properties and the characteristics of the biodiesel used [27]. These deviations are acceptable [28]. Especially since the effect of fuel on engine power and the torque to be developed by the engine makes more sense in terms of comparing the results, the fact that the values found are similar to those in the literature is an indicator that the mixtures are selected correctly [29, 30].

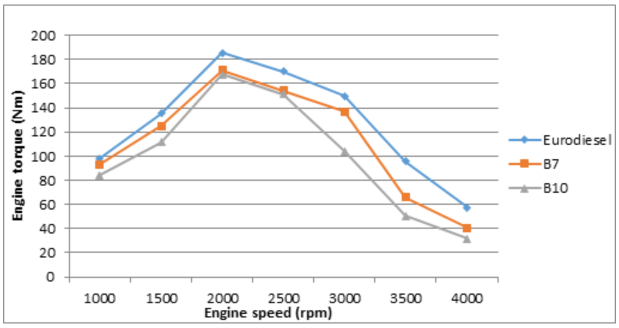


Figure 3. Changes of engine torque values according to engine speed

Figure 4 shows the changes in specific fuel consumption depending on engine speed. As can be seen, the lowest specific fuel consumption was achieved in all fuels in the range of approximately 2000-2500 rpm. When the chart is examined, it is seen that the lowest values are in eurodiesel use. Specific fuel values were approximately 25% higher when using biodiesel mixtures. Due to the low lower heating value of biodiesel mixtures, sending more fuel from the pump to obtain the power close to eurodiesel fuel causes increases in specific fuel consumption. Similar results were obtained with reported various studies by another researcher.

The specific fuel consumption is an important indication that the experiments are carried out correctly to be in line with the values found for engine power and torque. It is already a known feature that the specific fuel consumption in biodiesel mixtures is higher than diesel fuel since the calorific value of biodiesel fuel is lower compared to diesel fuel [23, 25, 31, 33].

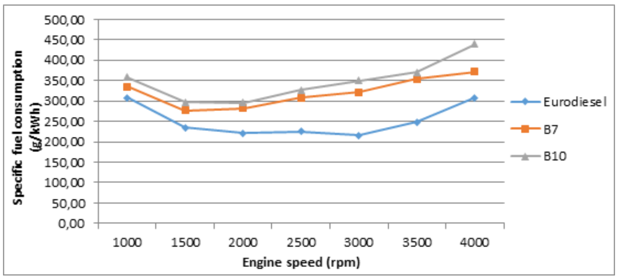


Figure 4. Changes of specific fuel consumption values according to engine speed

The main reason for the presence of CO among combustion products is insufficient oxygen or lack of complete combustion. In Figure 5, the change of CO% values in the exhaust gases according to engine speed is given. When the graph is analyzed, it is seen that as the engine speed increases, the amount of CO also increases. It is observed that CO values decrease more than 28% in B10 fuel use. The most important reasons for the decrease are the presence of oxygen in the molecular structure of biodiesel fuels and the higher air excess coefficients compared to diesel fuel during use in the engine. These two factors were effective in CO_2 conversion by oxidizing CO emissions during combustion.

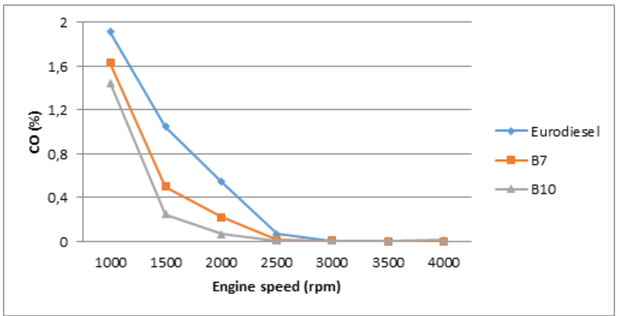


Figure 5. CO change according to engine speed

The change of CO_2 values in exhaust gases according to engine speed is included in figure 6. Increased CO_2 in exhaust gases indicates a good burn. CO_2 emissions increased by up to 14% with the use of biodiesel and Eurodiesel mixtures. CO_2 among exhaust products is an important parameter since it expresses complete combustion. The reason for the high CO2 emission in biodiesel blends and B10 fuel is the presence of oxygen in the biodiesel fuel and the higher air excess coefficients compared to the diesel fuel. Similar results were obtained in the studies by another researcher [6-8, 23].

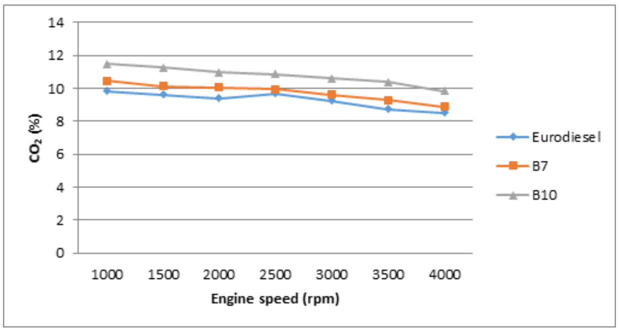


Figure 6. CO_2 change according toengine speed

HC refers to unburned fuel [32, 33, 34]. Figure 7 shows the change of HC values according to different engine speeds when using biodiesel-eurodiesel mixtures. The lowest HC value was measured in the use of B7-B10 fuel. HC values decreased more than 50% in the use of biodiesel fuel. The reason for the formation of hydrocarbons among unburned products is that the fuel does not oxidize or is semi-oxidized due to the fuel not reaching the ignition temperature or insufficient. Shortly, HC emission refers to unburned fuel.

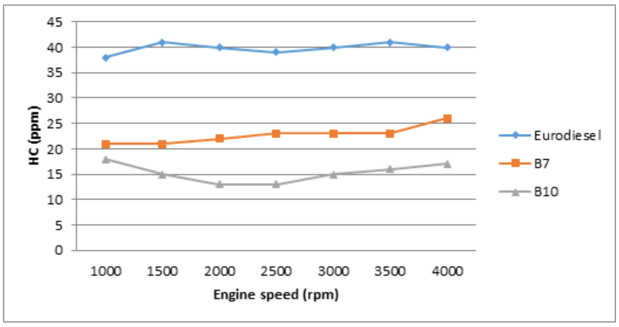


Figure 7. HC change according to engine speed

Figure 8 shows the change of NOx values according to engine rpms. The highest NOx values were measured using B10 fuel. NOx values increase up to 30% in the use of this fuel. The high temperature resulting from the combustion of the fuel in the engine creates nitrogen oxides by combining the nitrogen in the air with oxygen. In addition, as the combustion time of fast-igniting fuels increases, NOx levels increase. Depending on the oxygen content of biodiesel fuels, NOx emissions may increase compared to diesel fuel values. Because oxygen increases the combustion efficiency, the temperature at the end of the combustion increases and it can be effective in the oxidation of nitrogen gas to NOx emissions. Similar results were obtained in the studies with reported various studies by another researcher [2, 6, 11, 13, 23].

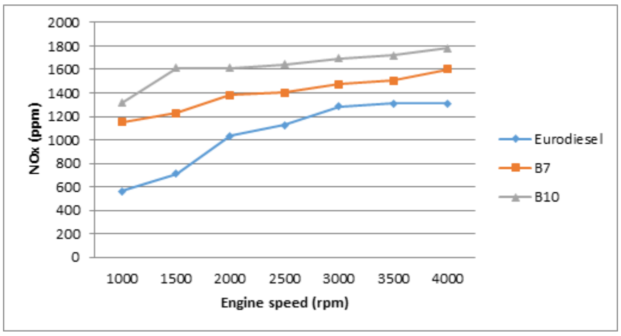


Figure 8. NO_x change according to engine speed

When the emission values are analyzed, it can be seen that CO_2, CO, HC and smoke emission mixtures provide a serious decrease up to 2000-2500 rpm ranges in which the maximum torque value is obtained compared to diesel fuel. In NOx emissions, due to the chemical structure of the biodiesel, an increase is observed in biodiesel mixtures up to 2500 rpm. After this value, it shows a stabilization even if it is more than diesel fuel. This is already anticipated [38-43].

Combustion characteristics were examined with the values obtained from the in-cylinder pressure sensor. As a result of the combustion of the fuel, the distribution of the mechanical loads occurring in any cylinder in an internal combustion engine according to the crank angle is expressed by the cylinder gas pressure curves [35]. In the in-cylinder pressure measurement, the data were recorded for 120 cycles at every 0.5 degree of the crankshaft and their arithmetic averages were taken. In-cylinder gas pressures of the engine used in the experiment were measured at 2500 and 4000 rpm, which are the maximum torque and speeds close to the maximum power used in cycles. Figure 9 and Figure 10 show the variation of in-cylinder gas pressure values of different engine speeds according to the crank angle [44, 45].

When we look at the in-cylinder pressure values, peak cylinder pressure values at 2500 and 4000 rpm revolutions occurred at approximately the same crank angle, after top dead center (ATDC) 10o. When the figure is examined, the maximum in-cylinder pressure value was obtained as 72 bar in Eurodiesel fuel at 2500 rpm. In the same cycle, 71 and 68 bar in-cylinder pressure values were obtained for B10 and B7 fuels.

At 4000 rpm, the in-cylinder pressure values were obtained as 80, 77 and 75 bar in eurodiesel, B10 and B7 fuel mixtures, respectively. In addition, even though the highest cylinder pressure values were obtained in eurodiesel fuel mixture at all revs, the maximum cylinder pressure values for all tested fuels are close to each other.

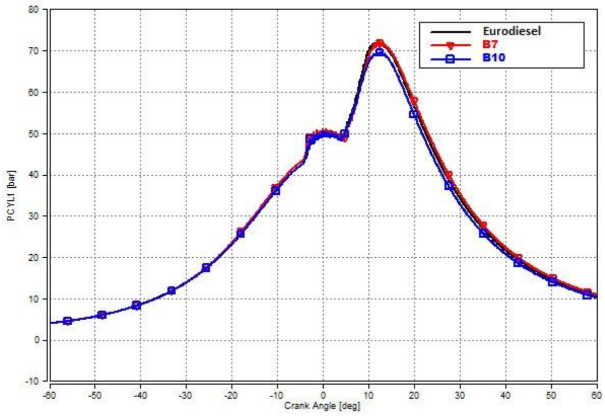


Figure 9. Change of cylinder gas pressure values according to crank angle (2500 rpm)

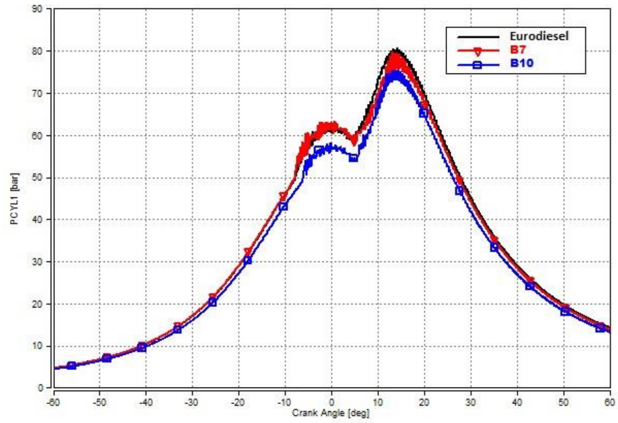


Figure 10. Change of cylinder gas pressure values according to crank angle (4000 rpm)

4. Conclusions

In this study, biodiesel produced from walnut oil and eurudiesel fuels were used. Biodiesel fuel mixture obtained with Eurodiesel fuel and B7 and B10 blends were prepared. Biodiesel fuel mixtures were used separately in the engine with common rail type fuel system without any changes. The engine performance and emission characteristics of these fuels were tested at different engine speeds and under full load. In accordance with the experimental results, engine performance and emission change graphs of each fuel were get and these graphs were compared with everyone.

When biodiesel is used, the main factor in the changes observed in engine performance is that the calorific value of the fuel is lower than eurodiesel fuel. Engine power has increased as the oxygen contained in biodiesel improves the oxidation of the fuel under partial load conditions. While the changes in emission values are in harmony with the reference fuel eurodiesel in terms of the emissions produced by alternative fuels, they create differences in the rate of increase and decrease. Since the engine used in the experiments keeps the fuel under very high pressure thanks to the Common-rail fuel system, HC emissions are lower than other fuels compared to eurodiesel fuel. At the same time, other fuels were lower in CO and CO_2 emissions compared to eurodiesel fuel. In the use of biodiesel, there has been an increase in the amount of NOx and O_2 in the exhaust gases due to the presence of oxygen in the fuel content. In this study, it was seen that the amount of NOx in the exhaust gases was mostly in B100 fuel.

As a result, since biodiesel and its blends have a higher viscosity and a lower ignition delay, combustion is lower at low speed and faster at high speed. In addition, combustion was rapid, as fuel evaporation would be easier with the increase of air speed at high revs. As a result, the amount of burning mass increased. The amount of mass burned is greater than that of biodiesel compared to diesel fuel. This is because the evaporation of biodiesel is lower than that of diesel. Another reason is that biodiesel burns faster than mineral diesel, due to its high oxygen content.

The use of biodiesel produced from walnut oil and its mixtures with eurodiesel fuel as an alternative fuel in diesel engines will be effective in reducing foreign dependency in energy. It will also contribute to the creation of new work areas. As a result, the use of vegetable oil and waste vegetable oil as an alternative fuel for diesel engines has a positive effect on both the environment and the economy.

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