

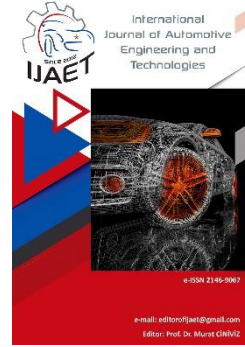


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Original Research Article



Investigation of the effects of camelina sativa biodiesel and eurodiesel blends on vehicle performance and emissions

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ABSTRACT

Studies have been conducted on improving engine performance, reducing environmental pollution caused by vehicles, and using alternative fuels. In the study, tests are carried out in a laboratory environment to check whether the engine has reached the intended use. Testing of internal combustion engines is crucial to research and teaching, trade and environmental pollution. Depending on the purpose of the test, the type and duration of vehicle tests will vary. Automobile manufacturing companies and research units will conduct a series of scientific and long-term tests in the vehicle development process. Thanks to engine and vehicle tests under different operating conditions, the measured values such as economy, power, moment, emission are compared with performance curves.

In this study, biodiesel was obtained from crude camelina sativa oil using the transesterification method. Camelina sativa biodiesel was mixed with Eurodiesel at the rate of 7% (B₇), 20% (B₂₀) and 50% (B₅₀). Vehicle performance measurements of biodiesel-Eurodiesel blends were made on a vehicle with four-stroke, four-cylinder, Common-rail fuel system, turbocharged and water-cooled engine using a chassis dynamometer. Vehicle performance and exhaust emissions were measured at different speeds during the vehicle chassis dynamometer test. While the highest moment value was obtained at 80 km/h in B₇ fuel, the maximum engine power was obtained in B₇ fuel at 160 km/h.

Average engine power and maximum engine torque of B100 fuel decreased by 3,28% and 10,21% compared to Eurodiesel fuel. As the rate of biodiesel increased, specific fuel consumption increased. The highest specific fuel consumption was obtained with 91,6 g/kWh in B100 fuel at 160 km/h. The average specific fuel consumption of B100 fuel increased 38,5% compared to Eurodiesel fuel.

When we look at the results of exhaust emission measurements, it is seen that camelina sativa biodiesel and fuel mixture decreased CO, CO₂ and HC values compared to Eurodiesel fuel, but increased NO_x values.

Keywords: Biofuel, Chassis Dynamometer, Engine Performance, Emission, Camelina Sativa

1. Introduction

According to the recent increase in oil consumption, many concerns have arisen about

the future of fuel, which is the main energy source. Until now, energy demands have been met with the use of fossil resources that led to

the depletion of these reserves. In addition to the depletion of these reserves, adverse environmental impacts such as global warming, ozone depletion and deforestation have led to the urgent need to use alternative energy that will be economically efficient, environmentally friendly and socially equitable [1]. Due to the steady increase in fuel demand and the increasing number of vehicles and people today, these expectations may remain unchanged for decades to come. Prices of fossil fuels are expected to rise as the demand for fossil fuels increases significantly and resources are beginning to run out. As a result, the expected scarcity of fossil fuels and the negative environmental impacts from the use of fossil fuels have led to research on renewable transport biofuels [2-5].

Studies have been conducted on improving engine performance, reducing environmental pollution caused by vehicles, and using alternative fuels. In the study, tests are carried out in a laboratory environment to check whether the engine has reached the intended use. Testing of internal combustion engines is crucial to research and teaching, trade and environmental pollution [6]. Depending on the purpose of the test, the type and duration of vehicle tests will vary. Automobile manufacturing companies and research units will conduct a series of scientific and long-term tests in the vehicle development process. These tests can often be performed on newly developed engines. During the manufacturing phase, the engine and vehicles are tested at the end of the assembly line. These tests are extremely important in terms of controlling the production. Similar tests are performed on the newly developed engine and vehicle and it is investigated whether the results reach satisfactory values. In addition, some engine tests have been carried out to determine the quality of fuel and engine oil and these test are used for educational purposes. Test results are the basis for the design and manufacture of the engine and experiments are carried out to check whether the engine provides the required power. Engine power and economy under different operating conditions are evaluated through engine specifications (i.e. performance curves). Thanks to engine and vehicle tests, the measured values such as economy, power, moment,

emission are compared with performance curves [7-9].

The unbalanced distribution of fossil fuels, which make up the largest part of primary energy resources, has caused some disadvantageous countries to become dependent on advantageous countries. This dependency is increasing day by day as the demand for energy increases. For this reason, countries are now looking for ways to utilize their energy resources, reduce dependence on foreign countries, and diversify their energy resources to ensure supply and demand security [10-12].

The nature produces 150 billion tons of biomass annually and only 10% of this biomass is used for commercial purposes. Now, the world is trying to stimulate this great potential, and biomass technology is rising significantly. While biofuels have become vital in providing energy supply and dealing with global warming, they have become the focus of attention of people around the world and measures for future generations are increased [13]. Environmental awareness is directly related to the economic and welfare levels of the countries. Therefore, the amount of harmful substances in the exhaust emissions of economically developed countries is determined by the standards. Today, LPG injection system has been developed in parallel with the gasoline injection system [15].

Biodiesel is the fuel used instead of Eurodiesel. It is a fuel that is formed as a result of the reaction with methanol (short-chain alcohol) by adding catalysts to vegetable oil or animal oils obtained from oil plants such as canola, sunflower, corn, cotton, camellia. Waste frying oils and oils of animal origin can also be used as raw materials for biodiesel [15].

Biodiesel does not contain petroleum products, but can be used as biodiesel or mixed with various proportions of Eurodiesel (Diesel). Unadulterated biodiesel and Eurodiesel-biodiesel blends are replaced in a Euroiesel engine with elements that won't be corroded by biodiesel and they become useful. Biodiesel is named as B₇: 93% Eurodiesel - 7% biodiesel B₂₀, B₅₀, B₁₀₀ according to its mixture with Eurodiesel. The most suitable B₂₀ mixture is considered to have commercial value, as these ratios affect the environment, economy, exhaust emissions and fuel properties [16-19].

This study was carried out to determine the

engine performances and exhaust emission values of Eurodiesel and camelina sativa biodiesel in different blends and different vehicle speeds with a vehicle dynamometer and to compare these values with the Eurodiesel fuel of a vehicle with Eurodiesel fuel system.

2. Material and Method

In this study, Selçuk University Technology Faculty, Mechanical Engineering Biofuel Laboratory was used to produce biodiesel from camelina sativa oil. Camelina sativa biodiesel obtained from camelina sativa oil was used in the 2012 Toyota brand Verso 2.0 type vehicle with 2000 cc turbo-charged Common-rail Eurodiesel fuel system at Selçuk University, Faculty of Technology Automotive Department. The technical characteristics of the engine belonging to this vehicle are given in Table 1.



Figure 1. Experiment setup and vehicle

Table 1. Technical characteristics of the test vehicle [20]

Specifications	Descriptions
Brand	Toyota
Model	Verso 2.0
Drive shape	Front wheel drive
Year of manufacture	2012
Wheelbase	2780
Vehicle length / Width / height (mm)	4440/1790/1620
Maximum vehicle weight (kg)	1540
Vehicle engine characteristics	
Number of cylinders	4
Diameter x stroke (mm)	86x86
Engine volume (cm ³)	2000
Number of valves	16
Compression ratio	15:8
Fuel system	Eurodiesel-Commonrail
Maximum power (kW-d/d)	92.46-3600
Maximum torque (Nm-d/d)	300-2400
Emission standards	
CO ₂ Emissions (g/km)	143 (Euro 5)

While preparing Eurodiesel fuel blends and camelina oil methyl ester, 93%, 80%, 50% and 0% Eurodiesel was added and then 7%, 20%, 50% and 100% biodiesel mixture was obtained respectively, which will provide the mixture by volumetrically. To determine the viscosity, density, thermal value and flash point values of the B₇, B₂₀, B₅₀, B₁₀₀ and Eurodiesel fuel obtained from the mixtures, the measurements were made in the Biodiesel Laboratory of Agricultural Machinery Department at Selçuk University, Agricultural Faculty. The experimental setup is given in Figure 1 below.

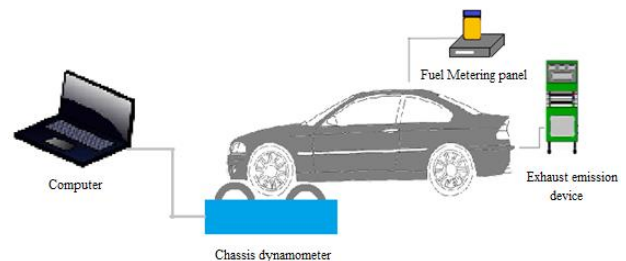


Figure 1. Experimental test setup

In the experiments, the HPT 6100 brand chassis dynamometer was used. The vehicle dynamometer can perform road test, power test and speed test [21]. The technical information of the Chassis Dynamometer device to be used in the experiments is given in Table 2. Properties of camelina biodiesel and test method types are given in Table 3.

Table 2. Technical characteristics of the chassis dynamometer [22]

Specifications	Unit	Descriptions
Brand		HPT
Model		6100
Drum Diameter	m	1,2
Max Speed	km/h	200
Maximum axle load	kN	35
Capacity	kW	170

2.1. Biodiesel production from camelina oil

Although biodiesel is produced by various methods, the most widely used method today is the transesterification method. This method; It is the process of re-esterifying vegetable oil by reacting a catalyst with alcohol. This method is the most effective method in reducing viscosity today [24]. Biodiesel production; It consists of 6 stages: mixing alcohol and catalyst, reaction, separation, washing, drying and storage [25]. The following items have been made in the production of biodiesel;

- Heating was made up to 60 °C by mixing the oil in the reactor.

Table 3. Properties of B100 camelina biodiesel [23].

Specifications	Unit	EN 14214:2010	Camelina biodiesel	Test method
Density 15 °C	kg/m ³	860–900	885 -888	EN ISO 12185
Kinematic viscosity (40 °C)	mm ² /s	3,5–5	4,53 – 5,45	EN ISO 3104
Cold filter plugging point	°C	-	-3	EN 116
Cloud point	°C	-	3	ASTM D 2500
Methyl ester content	(wt %)	96,5	97,5	EN 14103
Flash Point	°C	101	202	EN ISO 3679
Sulfur content	mg/kg	10	0,59	EN ISO 20846
Carbon residue	wt.%	0,3	0,019	EN ISO 10370
Water content	mg/kg	500	120	EN ISO 12937
Copper corrosion test (3 h, 50 °C)		1	1A	EN ISO 2160
Oxidation stability (110 °C)	h	6	1,3 – 2,2	EN 14112
Acid value	mg KOH/g	0,5	0,36	EN 14214
Iodine number	g.I ₂ /g	120	154	EN 14111
Thermal Value	(MJ / kg)	-	36,81	EN 50082

Table 3. Measured values in Eurodiesel and biodiesel blends

Biodiesel	B7	B20	B50	B100	Eurodiesel	Standard
Density	834	845,9	865,6	884,8	824,9	EN ISO 12185
Flash Point (°C)	164	175	186	205	65	EN ISO 3679
Kinematic viscosity (40 °C) mm ² /s	2,832	3,18	4,25	5,16	2,82	EN ISO 3104
Thermal Value (MJ/kg)	37,57	37,42	37,09	36,81	47,14	EN 50082

- 20% methanol by volume of camelina oil and 3,5 g NaOH catalyst per liter oil were added and the reaction was carried out in two stages.

- In the reaction, firstly, methanol and NaOH catalyst were mixed and the methoxide solution was obtained and mixed by pouring into the camelina oil in the reactor. Mixing was done at 80 l/min for sixty minutes. At the end of mixing, the glycerin accumulated at the bottom of the mixture that was kept for at least two hours was removed.

- When the raw biodiesel in the reactor was kept for 1 day to cool down and the glycerin contained in it to settle to the bottom, the glycerin accumulated at the bottom was taken again.

- Pure biodiesel and distilled water at a temperature of 50 °C were mixed equally by volume, washed and left to rest for twelve hours to precipitate the water. At the end of the washing process, the unreacted fatty acids, alcohol, Na⁺ ions, catalysts and glycerin that could be in the structure of the biodiesel were removed.

After discharging the water accumulated at the bottom of the reactor, the water remaining in the biodiesel is heated and mixed at 100 °C for at least two hours, after which the desired biodiesel is obtained after evaporation. The properties of camelina biodiesel and Eurodiesel fuel blends obtained are given in Table 3.

2.2. Vehicle Tests

Before performing the experiment, the measurement equipment must be calibrated and the necessary maintenance and installation of the test vehicle has been brought to the values in the catalog and made ready for the experiment. In all experiments, before starting the measurement process, the vehicle engine and the test equipment connected to the vehicle must be run and the vehicle engine must reach its operating temperature. In the experiment, engine power and exhaust emissions were measured in fourth gear and at different vehicle speeds in accordance with the DIN 70200 standard.

The wheels of the vehicle are brought on the chassis dynamometer drums. The vehicle is fastened to the drums on the dynamometer with lashing belts. After the connection belts are passed in a suitable place on the lower swing, they are tied to the drum and the gap of the belts is removed. The clearance process is very important in terms of safety because the vehicle does not move left and right at high speeds. The measurement is started by starting the vehicle. Measurements are calculated by the computer using the formulas below.

2.3. Engine Power Calculation

The braked power refers to the shaft power of the engine and is defined by P_e . Shaft power is

the net or gross power obtained from the engine according to power standards. In comparing engines, this is the most important basis for comparison. The braked power can be measured with a dynamometer that loads the output shaft of the engine. The shaft power of the engine can thus be calculated by the formula below.

$$P_e = M * \omega \quad (1)$$

If the angular velocity of the shaft is unknown, the engine power can also be calculated using the rotational speed.

$$P_e = M * 2 * \pi * n \quad (2)$$

Explanations of the formulas;

P_e Shaft power (Nm/s = W)

M Moment (Nm)

ω Angular velocity of the shaft (rad/s)

n Rotations of rotation (1/s)

2.4. Engine Torque Calculation

The engine torque is defined by M and its SI unit is Newton meters or Nm. Moment defines the density of the combustion pressure created in the cylinder and its transmission to the crankshaft. Moment can be measured using the formula below.

$$M = F * r = P / \omega \quad (3)$$

or as a numerical value, moment

$$M = 9550 * P / n \quad (4)$$

Explanations of the previous formulas:

M Moment (Nm)

F Force (N)

P Power (kW)

r Radius (m)

ω Angular velocity (rad/s)

n Speed (min^{-1})

3. Result and Discussion

The vehicle was brought to full throttle in fourth gear by the operator. Maximum engine speed was 6500 rpm and speed indicator was as 160 km/h. When the message "Press the clutch pedal" was seen on the computer monitor, the clutch was pressed by the operator and the wheels were waited to stop by themselves. During deceleration, the brake should not be applied.

Figure 2 shows the engine power changes depending on the vehicle speed of the test

engine in the use of camelina sativa biodiesel-Eurodiesel fuel blends. Maximum engine power values obtained for Eurodiesel, B₇, B₂₀, B₅₀ and B₁₀₀ fuels were calculated as 99,6, 101,4, 101,2, 97,7 and 94,3 kW, respectively. Maximum engine power was measured as 101,4 kW at 160 km/h for B₇ fuel. It is thought that the decrease in engine power depending on the proportion of camelina sativa biodiesel in fuels may result from high density and viscosity of camelina biodiesel.

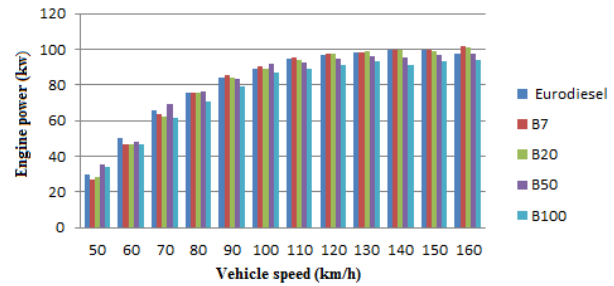


Figure 2. Engine torque change of fuels depending on vehicle speed.

The following equation is used for the uncertainty analysis of engine power in Eurodiesel.

$$w_R = \left[\left(\frac{\partial R}{\partial m} \cdot w_m \right)^2 + \left(\frac{\partial R}{\partial n} \cdot w_n \right)^2 \right]^{\frac{1}{2}}$$

$$w_R = [(2 * \pi * n * w_m)^2 + (M * 2 * \pi * w_n)^2]^{\frac{1}{2}}$$

In the Eurodiesel measurement results, it was seen that $M = 99,6$ kW, $n = 4924$ rpm and error rates were 3% from the catalog ($w_m = w_n$). When these values are inserted in the formula, the following results are obtained.

$$P_e = M * 2 * \pi * n = 99.60 * 2 * \pi * 4924$$

$$P_e = 3081465.083 \text{ W}$$

$$W_R = 92.83 = \pm \%3 \text{ value has been found.}$$

Figure 3 shows the change of engine torques for different fuels depending on the vehicle speed. Maximum engine torque values obtained for Eurodiesel, B₇, B₂₀, B₅₀ and B₁₀₀ fuels were calculated as 274, 277, 274, 265 and 253 Nm, respectively. Considering the experimental results, the highest torque value among all fuels was obtained in B₇ fuel at 80 km/h.

In the tests, the use of Eurodiesel fuel in terms of engine torque gave higher results than B₇, B₂₀, B₅₀ and B₁₀₀ fuels. With the increasing percentage of biodiesel in the mixture, the

torque values decreased. The fact that the torque values are lower results from the lower thermal value and high viscosity of biodiesel compared to Eurodiesel fuel. When the engine torque values are examined, it is seen that the study performed by [26, 27] is similar to the engine torque values.

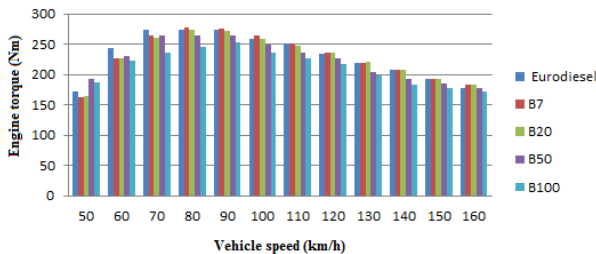


Figure 3. Engine torque change of fuels depending on vehicle speed.

Specific fuel consumption is expressed as the amount of fuel consumed per unit power. Figure 4 shows the effect of using biodiesel on specific fuel consumption. The minimum specific fuel consumption values obtained for Eurodiesel, B7, B20, B50 and B100 fuels were calculated as 57,63, 58,9,64,4, 72,9 and 82,4 g/kWh, respectively. In the tests, the lowest specific fuel consumption values for all fuels were obtained at a vehicle speed of 120 km/h with Eurodiesel, B7 and B100 fuels, but it was obtained at a vehicle speed of 100 km/h with B20 and B50 fuels. In general, specific fuel consumption has increased with the use of biodiesel. Specific fuel consumption increases with the increase in the amount of biodiesel in fuels.

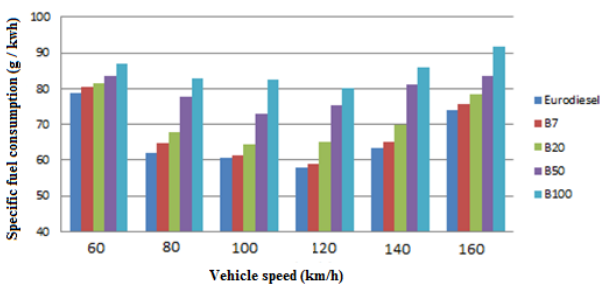


Figure 4. Specific fuel consumption variation depending on vehicle speed

When the fuel mixture is rich (e.g. starting or acceleration), CO emissions in the engine reach the highest level. Basically, CO formation depends on the excess air coefficient. CO emissions are one of the important parameters as they represent chemical energy loss that cannot be used in the engine [28-30]. Figure 5 shows how the CO value in the exhaust gas changes according to the vehicle speed when biodiesel-

Eurodiesel fuel mixture and Eurodiesel are used. According to the experimental results, the lowest CO emission value for each fuel was determined at a vehicle speed of 160 km/h. It has been observed that as vehicle speed increases, the air and fuel mixture is improved with better combustion effect and carbon dioxide emissions decrease.

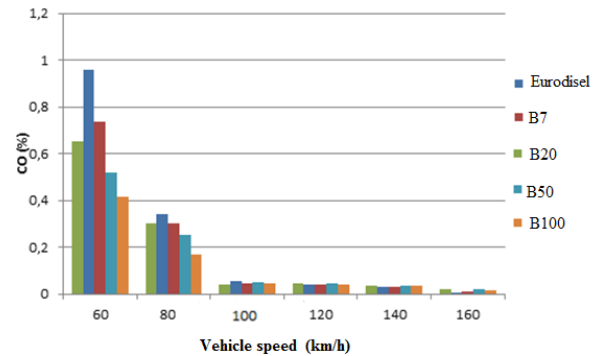


Figure 5. CO changes of fuels

Plants are living things that can capture CO₂ produced by burning renewable energy fuels. Plants convert CO₂ into carbon and oxygen. Thus, oxygen is released back to the atmosphere [31-33]. Therefore, the use of renewable energy provides a natural balance of CO₂ emissions. CO₂ in exhaust products is an important parameter as it represents complete combustion. Figure 6 shows the percentage of carbon dioxide as a function of vehicle speed. As it is seen in Figure 6, the CO₂ emission values measured during the experiment started to decrease as the biodiesel rate and vehicle speed increased. The highest CO₂ emission value was measured as 6,62% in Eurodiesel fuel at a vehicle speed of 100 km/h. The lowest was 4,21% in B100 fuel at a vehicle speed of 160 km/h.

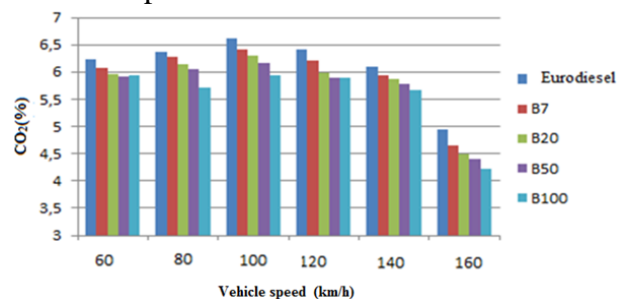


Figure 6. CO₂ changes of fuels

A high amount of O₂ in the exhaust indicates a poor mixing ratio. As the mixture gets poorer in Eurodiesel engines, fuel consumption decreases and other harmful emissions except NO_x also decrease.

High O₂ content in the exhaust gas indicates a

poor mixing ratio. As the mixtures in the Eurodiesel engine become poor, fuel consumption decreases and other harmful emissions apart from NO_x also decrease [34]. Figure 7 shows the amount of O_2 in the exhaust gas when biodiesel-Eurodiesel fuel mixture is used. The highest measured O_2 emission value was 16,72% in B100 fuel at a vehicle speed of 160 km/h. The lowest is 10,15% in Eurodiesel fuel at 60 km/h vehicle speed.

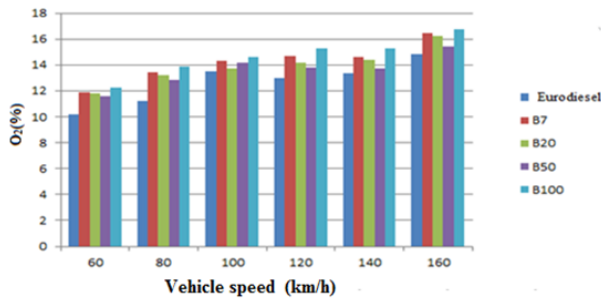


Figure 7. O_2 changes of fuels

The reason for the presence of unburned HC in combustion products is that the fuel cannot reach the ignition temperature, the oxygen is low or the fuel cannot be burned because the fuel cannot find sufficient burning time. Hence, HC refers to unburned fuel [35].

Figure 8 shows the change in HC value when biodiesel-Eurodiesel mixed fuel is used at different engine speeds. The highest HC values were measured as 19,29 ppm at 160 km/h when Eurodiesel fuel was used. The lowest measured HC value was found as 7,5 ppm at 80 km/h for B100 fuel.

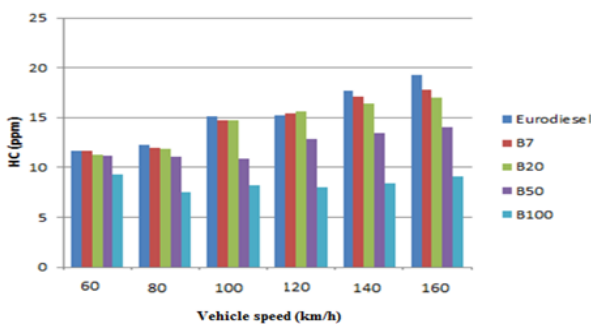


Figure 8. HC changes of fuels

NO_x is a general term given to emissions such as NO and NO_2 . NO_x emissions are significantly related to the temperature inside the cylinder, the combustion process, and the amount of oxygen that reacts with it during this reaction. It usually occurs in uncontrolled combustion in places with high temperatures. This is because vegetable oil contains oxygen. The high

temperature that occurs after the combustion of fuel in the engine produces nitrogen oxides by combining nitrogen and oxygen in the air. In addition, NO_x level rises due to prolonged combustion in fast-firing fuel. NO_x values are high due to the high oxygen temperature that plant-based fuels contain [34-36].

According to the data in the experimental results, the minimum NO_x emission values were determined for all fuels at a vehicle speed of 160 km/h. Since biodiesel fuel contains more oxygen than Eurodiesel fuel and the cylinder temperature rises, the use of biodiesel increases NO_x content. The highest NO_x value was measured as 527 ppm at 80 km/h in B100 fuel.

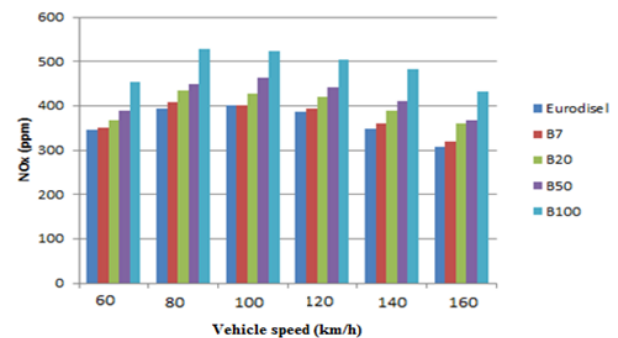


Figure 9. NO_x changes of fuels

4. Conclusions

There are few studies on fuel production from non-renewable plants, especially those that can grow easily on non-arable land, and the demand for irrigation and planting costs is not low.

For this purpose, biodiesel was obtained from *Camelina sativa* using the transesterification method. Using different ratios of Eurodiesel fuel in a four-cylinder compression ignition engine, the effect of *Camelina sativa* biodiesel on engine performance and emission values was studied. The following results can be obtained by comparing the obtained results with the data from standard Eurodiesel.

As a result, we can say that the reason for the increase of engine power in B50, B20 and B7 fuel mixtures compared to Eurodiesel fuel is that the oxygen content in biodiesel contributes to complete combustion. Since biodiesel with high cetane number shortens the ignition delay, a lower combustion temperature is achieved by reducing the amount of fuel in the pre-combustion stage.

Considering the emission values; CO , CO_2 and HC emission values decreased as the biodiesel

ratio and vehicle speed increased, but NO_x values increased. In terms of the importance of the country's economy, it is important to increase plant-based biodiesel fuel varieties and to grow plants for the production of biodiesel in the suitable areas where there is no plant growing process. In this way, this can contribute to the country and humanity. As a result, using biodiesel obtained from waste oil and vegetable oil as an alternative fuel in Eurodiesel vehicles can positively affect engine performance. Therefore, biodiesel especially reduces exhaust emissions. It reduces greenhouse gases that cause global warming by the use of biodiesel and gases that deplete the ozone layer in the atmosphere.

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