An Experimental Study of the Effects of Camelina Sativa Biodiesel-Diesel Fuel on Exhaust Emissions in a Turbocharged Diesel Engine

Hasan Aydogan, A. Engin Ozcelik, and Mustafa Acaroglu

***Abstract*—The aim of this study in diesel engines using fuel that can be produced with indigenous resources, renewable energy Camelina sativa biodiesel fuel, which is to investigate the use of the facilities. In recent years, both in the countries of the European Union, as well as the number of engine vehicles in Turkey diesel is increasing rapidly. Fossil fuels used in these engines work on the use of alternative energy sources are made. One of these alternative fuels, biodiesel. In this study, the use of fossil fuel diesel engines, which can be produced with indigenous resources, renewable energy Camelina biodiesel fuel, which was aimed to investigate the use of the facilities. In experiments diesel fuel and percent 20, 50 is used Camelina biodiesel blends. In experiments with common rail fuel system, turbocharged engine is used. Engine emissions of different fuel usage is examined.**

***Index Terms*—Biofuels, Camelina sativa biodiesel, engine emissions.**

I. Introduction

Industrial economy of a country is very much dependent on non-renewable fossil resources like coal, petroleum and natural gas with applications in electric generators, power plants, heavy trucks, locomotives and mining equipment. This ever increasing drift of energy consumption is not sustainable due to unequal geographical distribution of fossil fuels as well as environmental, geopolitical and economic concern [1]-[3].

Besides, use of fossil fuel triggers a huge amount of greenhouse gas and noise hence polluting the environment. This twin crisis of fossil fuel depletion and environmental degradation have motivated researchers to explore and evaluate the performance of alternative fuels such as biodiesel, bio hydrogen, bioethanol etc. in internal combustion engine [4]-[6].

Biodiesel can be used in modern unmodified diesel engines [7]. Therefore, it is a favor- able alternative to conventional energy sources, which will help to decrease the release of greenhouse gas [8], [9].

Camelina, which occurs naturally in the Mediterranean and Central Asia is annual herbaceous plant. Is a plant known since year 3000, Europe was produced until 1960. Then, this plant is replace of rapeseed. Camelina plant in Turkey, Japan and the United States Camelina oil is used as aircraft fuel was on the topic. Oil content of camelina seeds ranges from 25 to 45%. Camelina oil is 90% of unsaturated fatty acids, of which about 57% of polyunsaturated fatty acids (omega-3 and omega-6) is composed. Due to Camelina oil has got 2-6% erucic acid, it restricts the use edible. Soil requirements in terms of salinity and drought as being highly selective in terms of resistance from many oil plants are more tolerant [10].

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Today, diesel engines are widely used in transportation, industry and agricultural areas because of their high fuel efficiency and ease of operation. The demand for diesel engines has been continuing to increase worldwide as a result of expanding industrialization. This is because diesel engines have certain advantages compared to spark ignition engines such as low fuel consumption, high engine torque and longevity. Despite these advantages, today diesel engines are among the leading factors that cause air pollution. In our day, studies are conducted on changing certain engine operating parameters such as valve timing, injection timing and rate in order to decrease harmful emissions. In addition, researchers have been conducting studies on various renewable fuels such as biodiesel and alcohols because of the decrease in the reserves of fossil energy sources and their negative effects on the environment.

Biodiesel has received significant attention in all countries since it is nontoxic, biodegradable and renewable diesel fuel. Biodiesel is generally produced from cooking vegetable oils. Using high-quality virgin oils makes biodiesel more expensive than diesel fuel and it causes to increase in vegetable oil prices. Therefore, low cost feedstocks are needed and should be used in biodiesel production. In Turkey, B2 (2% biodiesel, 98% diesel fuel) usage is excise tax free for biodiesel produced from waste cooking vegetable oils. However, there are different biodiesel feedstocks to be used in the production. For example, rendered animal fats and leather industry wastes are appealing feedstocks to produce biodiesel so that there is no conflict with food production [7]-[9].

Cameline sativa yields anywhere from 336 to 2240 kg of seeds per hectare at maturity, with the lipid content of individual seeds ranging between 35 and 45 wt.% with 27–32 wt.% protein content. C. sativa oil contains approximately 90% unsaturated fatty acids. This unusual fatty acid pattern is due to the abundance of C18:1 (12.8– 14.7 wt.%), C18:2 (16.3–17.2 wt.%), C18:3 (36.2–39.4 wt.%) and C20:1 (14.0–15.5 wt.%) fatty acids. This level of unsaturation would most likely make the unhydrogenated oil unsuitable for food-related applications because the oil would likely be prone to autoxidation. In addition, the physiological effects of eicosenoic acid are not well understood [9], [10].

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Although CSB along with its properties have already been re- ported the present study provides a more comprehen- sive fuel property assessment not found in the literature to date. The aim of the present work was to conduct a complete character- isation of C. sativa biodiesel (CSB) according to the ASTM D6751 and EN 14214 standards. The standard requirements are based on the desire to ensure that biodiesel is of adequate purity, quality and stability to ensure engine and fuel component durability and reliability. For the first time, a set of thirty parameters was analysed. The values for six of these parameters, all directly related to the fatty acid profile, did not meet the standard requirements. These so-called structure indices originally served to exclude the use of certain vegetable oils or animal fats as feedstocks.

When previous studies were examined, it was seen that there were no studies on the use of camelina biodiesel in a diesel engine with a common rail injection system. In the present study, the effects of two different camelina biodiesel fuel ratios obtained through transesterification on engine emissions of these fuels compared to diesel fuel were examined.

II. Material and Method

A 1.9 multijet diesel engine was used in engine tests (Table I). The tests were carried out on the hydraulic engine dynamometer with the specifications presented in Table II. All the tests were conducted at full-throttle opening. Before starting the tests, the engine was operated until it reached a stable condition. Afterward, the experiments were started.

In the tests, NO_x, HC, CO_2 emission values of diesel fuel, B20 and B50 fuels were carried out by using Bosch BEA 350 model emission measurement test equipment (Table III). General view of the test platform is shown in Fig. 1.

TABLE I: Technical Specifications of the Test Engine

Engine	1.9 Multijet diesel engine
Cylinder number and layout	4, in-line transverse
Cylinder volume (cc)	1910
Compression ratio	18.5:1
Maximum power HP – rpm	105 - 4000
Maximum torque Nm (kgm) - rpm	200 - 1750
Fuel	Diesel
Fuel feed	Electronically controlled Common Rail type Multijet direct injection, turbo and intercooler
Ignition	Compression
Diameter x Stroke (mm)	82 x 90.4

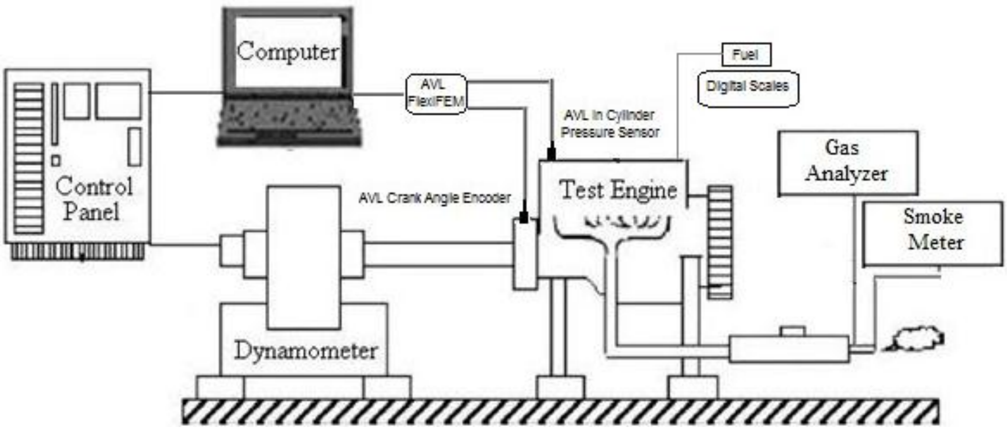

Fig. 1. Engine test equipment.

TABLE II: Technical Specifications of the Hydraulic Dynamometer Used in the Study

Brake model	BT-190 FR
Maximum brake power	100 kW
Maximum speed	6000 d/d
Maximum torque	750 Nm
Brake water operating pressure	0-2 kg/cm^2
Water needed for maximum power	2,3 m^3/hr
Brake water exit maximum temperature	80 ^{o}C
Torque measurement	Electronic load-cell
Rotation direction	Right and left rotation

TABLE III: Technical Specifications of the Exhaust Emission Measuring Device

Parameters	Measuring range	Precision
HC	0-20.000 ppm	1 ppm
CO_2	0-20%	0.1%
CO	0-15%	0.001%
O_2	0-21.7%	0.01%
NOx	0-5000 ppm	1 ppm

Diesel fuel and camelina oil were used as material in this study. The properties of raw camelina oil and diesel fuel are presented in Table IV. Camelina seeds obtained after the harvest were subjected to hot press at 85 ℃ to produce raw oil. The raw oil was filtered and biodiesel was obtained through transesterification by using methanol as alcohol and NaOH as catalyzer. EN 14214 standard test methods were taken as reference in measuring the obtained values.

The density measurement experiment was conducted by using the KEM Density/Specific Gravity Meter DA–505. The device operates through resonant frequency measuring method. The measuring range is 0-3 g/cm^3, operating temperature is 4-90 ℃, margin of error in density measurements is ±0.00005 gr/cm^3, manual measuring time is 1-4 minutes and 2-10 minutes in programming code.

The device used for kinematic viscosity measurement was Koehler K23377 model with operating temperature range between 25 and 150 ℃ and a temperature sensitivity of ±0.01. Viscosity measurement can be performed according to ASTM D 445, DIN 51550 and ISO 3104 standards.

TABLE IV: COMPARISON OF THE PROPERTIES OF RAW CAMELINA OIL AND DIESEL FUEL

Properties	Raw camelina oil	Diesel
Density 15 ℃ (kg/m^3)	918	838
Kinematic viscosity 40 ℃ mm^2/s	24	2.92
Flash point ℃	>220	102
Lower heating value (MJ/kg)	38	42.3
Ash (% mass)	0.0025	0.01
sulfur (mg/kg)	13.85	9
Water content (mg/kg)	710	43.8
Acid value (mg KOH/g)	1.39	-
Iodine number (g.I$_2$/100 g)	151.5	-

All the tests were conducted at full-throttle opening. Before starting the tests, the engine was operated until it reached a stable condition. Afterwards, the experiments were started. All the experiments were repeated for three times and means of the obtained values were calculated.

III. RESULTS AND CONCLUSION

CO_2 is a natural gas that forms as the result of burning. However, increasing amounts of CO_2 in the atmosphere causes the formation of greenhouse gasses and global warming. CO_2, which is among exhaust products, is a highly important parameter since it represents full combustion [11].

The CO_2 values of fuels with respect to engine speed are given in Fig. 2. The results show that the CO_2 emission values of diesel fuel are on average 20% less compared to those of B7 and B100 fuels. Biodiesel contains oxygen. For this reason, extra oxygen is added to the air taken into the cylinder. Combustion improves with the increase of the amount of O_2 taken into the cylinder and the amount of CO_2 that occurs as the result of the process also increases.

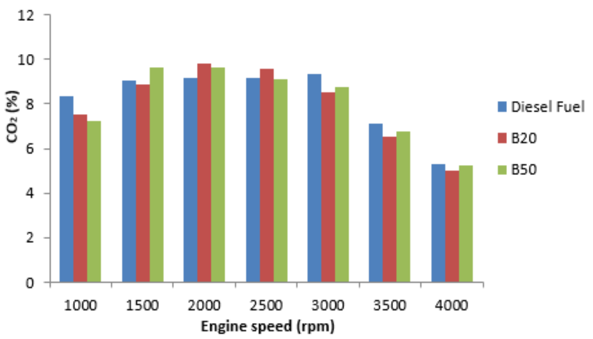

Fig. 2. CO_2 emissions in diesel fuel and biodiesel blends.

HC represents unburned fuel. HC values of the fuels with respect to engine speed are given in Fig. 3. HC value of B7 fuel was found to be 37.5% lower and HC value of B100 fuel was found to be 68.8% lower compared to that of diesel fuel. These values are compatible with the amount of CO_2 in the exhaust gas. As can be seen from the ratios, HC emission decreased as blend ratio increased. The primary reason for the decrease in HC emissions is that the oxygen content of biodiesel maintains adequate oxidation, that is, burning in rich air-fuel mixture zones. High HC emissions at low engine speeds is because of the fact that specific fuel consumption is also high at these engine speeds. Engine type also has an effect on these values [12]. High engine compression ratio is also among the factors that cause high HC emissions.

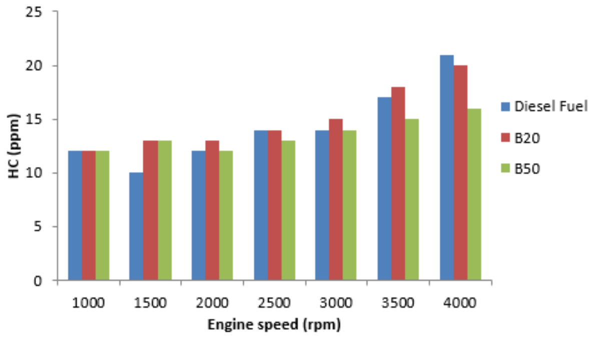

Fig. 3. HC emissions.

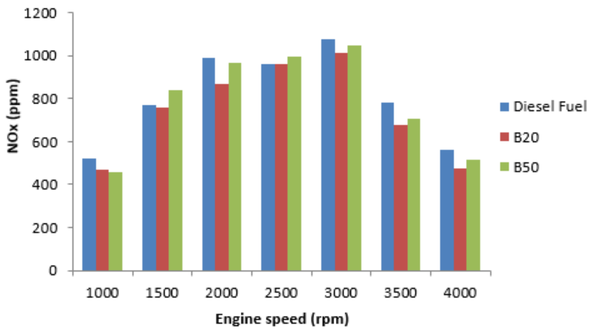

Fig. 4. NO_x emissions.

In engines, the combination of the nitrogen in the air with oxygen at high temperatures reached as the result of combustion decreases NO_x emissions [13]. For this reason, real NO_x values were found by using the humidity correction factor defined by SAE 2001 [14]. The NO_x values of the fuels with respect to engine speed are presented in Fig. 4. NO_x values were found to be 17.6% higher in B20 fuel and 58.8% higher in B100 fuel on average compared to diesel fuel. For NO_x formation, N, O_2 and high temperature are needed in the environment. During the combustion process, oxygen and nitrogen reacts with each other at high temperatures and this reaction causes NO_x emissions. Main part of NO_x emissions consists of NO emis- sions while NO_2 emissions are the small part of NO_x emissions. The rest trace amount of NO_x emissions are composed of other oxygen–nitrogen combinations. The emissions of NO_x emissions are mainly due to oxygen in air. However, some diesel fuels may have trace amount of nitrogen molecules in their structure but the nitrogen content in the fuel have little effect on NO_x emissions. The emissions of NO_x depend on cylinder temperature, pressure, air–fuel ratio and combustion duration. In addition, some fuel proper- ties such as viscosity and bulk modulus also affect the NO_x emissions. Humidity has an important effect on NO_x emissions. An increase in air humidity causes a reduction in NO_x emissions. Therefore, humidity values were measured to do humidity correction during all engine tests. The amount of NO_x increases as the amount of O_2 increases in the environment. The increase in NO_x here can be explained by the O_2 content of biodiesel. Furthermore, specific fuel consumption of biodiesel blends is higher compared to that of diesel fuel and the oxygen content increases the oxidation in fuel-rich zones, which increases the number of combustion zones. The increase in the number of zones with high environmental temperature also increased the formation of NO_x emissions [15].

IV. CONCLUSION AND SUGGESTIONS

In the present study, engine emission were examined in a four-cylinder, water-cooled, four-stroke, turbo charged, intercooler, common rail fuel system diesel engine. Camelina biodiesel (B20 and B50) and diesel fuel blends were used as test fuel. The obtained results were compared with those of diesel fuel. The main results were obtained as follows:

- CO_2 emission of diesel fuel was found to be approximately 20% lower compared to that of B20 and B50 fuels. The reason for this difference is that as the oxygen content of biodiesel increases, combustion improves and the amount of CO_2 formed also increases.
- HC values of B20 fuel decreased 37.5% compared to diesel fuel and HC values of B50 fuel decreased 68.8% compared to diesel fuel. As the blend ratio of biodiesel increases, the oxygen content of biodiesel maintains adequate oxidation, that is, burning in rich air-fuel mixture zones.
- NO_x values were found to be 17.6% higher with B20 fuel and 58.8% higher with B50 fuel compared to diesel fuel. The increase in the number of zones with high environmental temperature also increased the formation of NO_x emissions.
- C. sativa contains a high percentage of oil (>40 wt.%) that can be easily extracted and refined. Moreover, this oil can be easily transesterified using homogeneous alkali catalysis. However, the obtained biodiesel does not meet all of the quality specifications in the EN 14214 and ASTM D6751 standards. C. sativa biodiesel pre-sents serious drawbacks for biodiesel applications; the linolenic acid methyl ester content, polyunsaturated (P4 double bonds) methyl ester content, iodine value, cetane number and oxidation stability do not satisfy the limits of EN 14214.

When the results obtained in this study and similar studies are examined, different blends of biodiesel are highly important in terms of engine emissions when the concepts of environment and sustainability are taken into account.

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