Performance and Emissions of a Single Cylinder CI Engine Running on Corn Oil Methyl Ester-Diesel Blends

Abdülvahap Çakmak and Atilla Bilgin

Abstract—**This document presents an experimental study on performance and emissions of a single cylinder, direct injection CI engine fueled with corn oil methyl ester-diesel blends. The blend fuels contain corn oil methyl ester with ratios of 10% (B10), 20% (B20) and 50% (B50) on volume basis, respectively. Engine experiments were carried out an existing test unit for five different engine speeds at full throttle position. The results showed a reduction in engine torque and brake specific fuel consumption (BSFC) with increasing biodiesel percentage in the blend fuels except for B10. Blend fuels result in higher thermal efficiency than diesel fuel. The mean thermal efficiency of the engine by using diesel, B10, B20 and B50 were determined as 37.57%, 38.95%, 38.19% and 38.22%, respectively. Also, blend fuels gave less CO and O_2 emissions but higher NO_x, HC and CO_2 emissions compared to diesel fuel. It was calculated that NO_x emissions of B10, B20 and B50 were 16.25, 9.48 and 38.84% higher than diesel fuels, respectively.**

Index Terms—**CI engine, corn oil methyl ester-diesel blends, engine performance, emissions.**

I. Introduction

The limited reserves of the fossil fuels, their increasing cost and a major contribution to the emission of combustion-generated pollutant have led biofuels more attractive [1]. Among the biofuels, biodiesel is the most appropriate alternative fuel because of its good fuel properties, engine performance, and emissions and it's substitution for diesel fuel in a diesel engine without any engine modification. Biodiesel can be produced from edible and non-edible vegetable oils, animal fats and waste oils. Biodiesel is non-toxic, biodegradable and environmentally friendly fuel [2]. Hence, production and consumption of the biodiesel have increased day by day, over the world. The EU is the world's largest biodiesel producer. Biodiesel is also the most important biofuel in the EU and, on energy basis, represents about 80 percent of the total transport biofuels market [3]. In the EU biodiesel consumption reached 13,060 million litters in 2015 [3]. In Turkey, Energy Market Regulatory Authority made it compulsory to blend domestically produced biodiesel to diesel fuel at least 3% by the January 1st, 2016.

Several authors have published works about investigation engine performance and emission of a diesel engine fueled with biodiesel which produced different feedstock and/or biodiesel-diesel blends. Generally, these studies point out that by using biodiesel or its blends with diesel fuel result less engine performance, higher BSFC and a considerable reduction in HC, CO and PM emissions, but an increase NO_x emissions in compared to diesel fuel [4]-[7].

In this study, corn oil is chosen as a raw material for biodiesel production which is abundant in Black Sea Region of Turkey and also it has a potential to be used as feedstock for biodiesel production in Turkey. Therefore, it needs to be determined the effects of corn oil biodiesel-diesel blends on a diesel engine's performance and exhaust emissions.

Authors are willing to contribute to the literature by investigation the influence of corn oil methyl ester-diesel blends on engine performance and emissions.

II. Experimental Equipment and Test Procedure

Experiments were conducted on existing experimental setup at the Mechanical Engineering Department of Karadeniz Technical University. The experimental setup consists of a diesel engine, an engine test bed and a gas analyzer. A schematic view of the experimental setup is shown in Fig. 1. The engine used in this experiment was a single cylinder, natural aspirated, direct injection diesel engine with a cylinder bore of 88 mm, a stroke of 76 mm and a compression ratio of 20.5:1. The maximum power of the test engine is 7.3 kW at 3600 rpm. There is not any modification of the diesel engine. The experimental setup enables accurate measurement of engine torque, engine speed, air mass flow rate, fuel volume flow rate and all the relevant temperatures and pressures. Exhaust gasses were measured by Bilsa MOD 2210 gas analyzer. Measurements range and accuracies of the gas analyzer are given in Table I. Engine tests were performed for five different engine speeds, namely 1000, 1500, 2000, 2500 and 3000 rpm at full throttle position. Test data were recorded by versatile data acquisition system with a 0.5-second interval during 10 seconds and the mean values of the data were used for calculations. All measurements are conducted under steady state conditions. Accuracies of the measurements and the uncertainties in the calculated result are given in Table II.

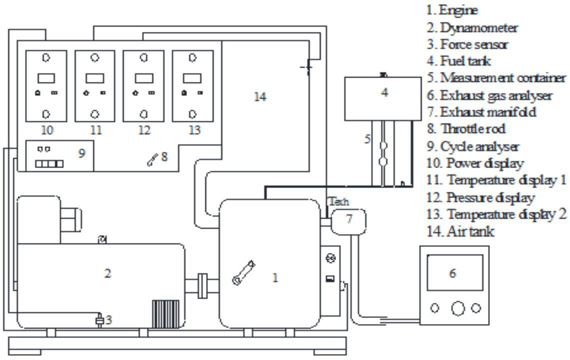

Fig. 1. A schematic view of the experimental setup.

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Biodiesel (corn oil methyl ester) was produced in the laboratory with biodiesel production machine from corn oil by a transesterification reaction with methanol (CH_3OH), where potassium hydroxide (KOH) was used as a catalyst. The reaction parameters giving the lowest kinematic viscosity were chosen as 1.1% catalyst concentration, 60 ℃ reaction temperature, 60 minutes reaction time and 9:1 alcohol/oil molar ratio [8]. Diesel fuel (Euro diesel) was purchased from a commercial supplier. Produced corn oil biodiesel was then mixed with diesel fuel by ratios of 10, 20 and 50% by volume designated as B10, B20 and B50, respectively. Some important properties of the test fuels such as density (ISO 4787), kinematic viscosity (DIN 53015), flash point temperature (EN ISO 3679) and lower heating value (DIN 51900-2) were measured in the Prof. Dr. Saadettin GUNER Fuel Research and Application Center at Karadeniz Technical University. Some fuel properties of the test fuels are shown in Table III.

TABLE I: SPECIFICATION OF EXHAUST GAS ANALYSER

Emissions	Measuring Range	Accuracy
CO	0-10% vol.	0.001%
CO_2	0-20% vol.	0.001%
HC	0-10000ppm	1 ppm
O_2	0-25%vol.	0.01%
NO_x	0-5000ppm	1 ppm

TABLE II: ACCURACIES OF THE MEASUREMENTS AND THE UNCERTAINTIES IN THE CALCULATED RESULT

Measurements	Accuracy
Engine speed	∓1 rpm
Engine torque	∓0.1 Nm
Temperature	∓0.1 ℃
Calculated results	Uncertainty
BSFC	∓0.6694%
Thermal efficiency	∓0.7065%

TABLE III: SOME FUEL PROPERTIES OF THE TEST FUELS

Properties	Diesel	B10	B20	B50
Density at 20 ℃, [kg/m^3]	826.379	831.767	836.357	852.322
Kinematic viscosity at 40 ℃, [mm^2/s]	2.8475	2.9326	2.9781	3.2342
Flash Point, ℃	63	74	90	-
Lower heating value, [kJ/kg]	42797	42224	41697	40048
Lower heating value,[kJ/L]	35367	35119	34874	34134

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the variation of engine torque with respect to engine speed for test fuels. It is seen from the figure that engine torque increase with increasing engine speed up to 2000 rpm, after 2000 rpm increasing the engine speed leads to a decrease engine torque, because of an increase in mechanical friction and a decrease in volumetric efficiency. Diesel fuel which has higher heating value than other fuels gives slightly higher torque output than the B20 and B50, generally. On average, the engine torque values are determined as 21.71, 21.75, 21.27 and 21.5 Nm for diesel, B10, B20 and B50, respectively. Although, the volume-based heating value of the diesel fuel is 0.71%, 1.41% and 3.61% higher than those of B10, B20 and B50, respectively, the torque value of the blends are very close to that diesel. The reason of this can be attributed to the oxygen content of the blend fuels which improve combustion efficiency and results in nearly the same engine torque output.

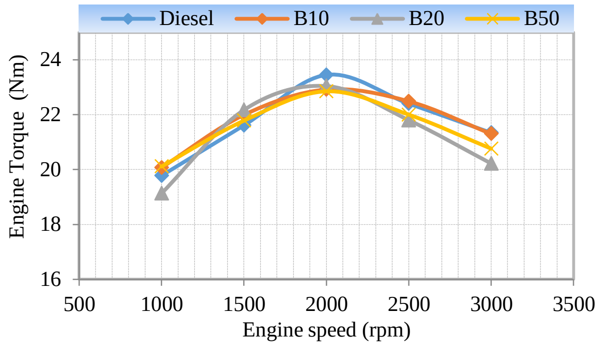

Fig. 2. Comparison of the engine torque for test fuels.

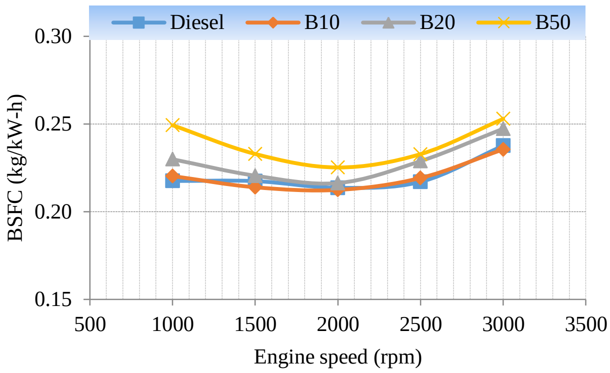

Fig. 3. Comparison of the BSFC for test fuels.

Brake specific fuel consumption (BSFC) is one of the basic performance characteristics used for comparing the effects of different fuel on engine performance [2]. The variation of BSFC for test fuels is illustrated in Fig. 3. As seen in the figure, the BSFC decrease with increasing the engine speed thanks to an increase in-cylinder turbulence [9] and fuel injection pressure which improve fuel-air mixture formation and this could be effective on decrease BSFC [5]. For diesel, B10, B20 and B50 the minimum BSFC are obtained at 2000 rpm as 0.2136, 0.2124, 0.2163 and 0.2252 kg/kW-h, respectively. At high engine speeds the higher mechanical frictions and less time for combustion cause an increase in BSFC. The BSFC values of biodiesel-diesel blends are higher than those of diesel fuel except B10. The increase in BSFC is expected since the heating values of the blend fuels are lower than those of diesel fuel as given in Table II. But, by using B10 the oxygen content and the lower viscosity (when compared to B20 and B50) of it may be the reasons of the minimum BSFC. On average, the BSFC values are determined as 0.221, 0.220, 0.229 and 0.239 kg/kW-h for diesel, B10, B20 and B50, respectively. In fact, the differences in BSFC values between diesel and B10 are negligible.

Fig. 4 shows the variation of exhaust temperature with respect to engine speed for test fuels. Exhaust temperatures of the test fuels increase with increasing engine speed due to more fuel consumption and shorter combustion duration at high engine speeds. Variation of the exhaust temperature for test fuels can be originated from the compositions of them. It is decelerated that biodiesel usually contains some constituents which have higher boiling temperatures and these constituents cannot evaporate completely during the main combustion phase but continue to burn in the late of combustion phase that causes a higher exhaust temperature [10]. On average, the exhaust temperature of B10, B20 and B50 were determined as 419.2℃, 425.2 ℃, 434.4 ℃ and 428.2 ℃, respectively. That is B20 gives maximum exhaust temperature while diesel fuel yields minimum exhaust temperature. As seen from here, exhaust temperature for blends fuels is not proportional to biodiesel contents in the blends fuel. This may attribute to different combustion characteristic of each fuel. A similar result can be found in the reference [11].

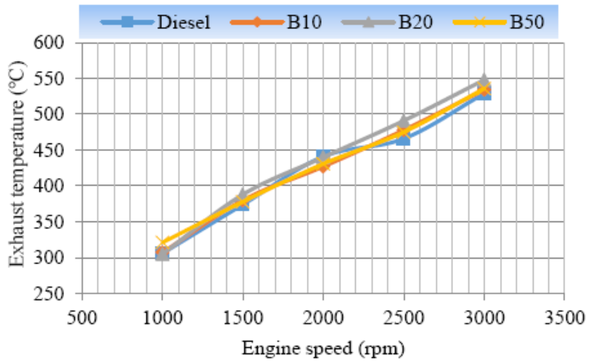

Fig. 4. Comparison of the exhaust temperature for test fuels.

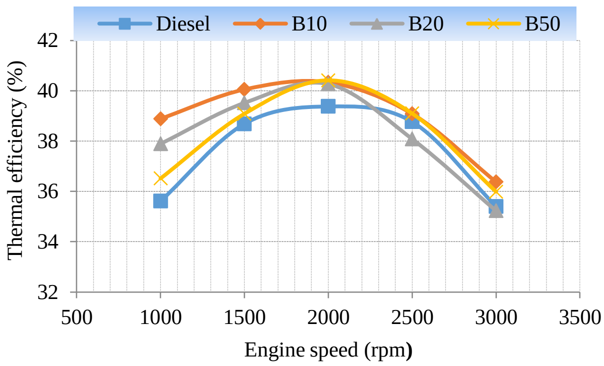

Fig. 5. Comparison of the thermal efficiency for test fuels.

The brake thermal efficiency of the engine for test fuels is shown in Fig. 5. The brake thermal efficiency is defined as the ratio of the net power output to fuel energy rate enters in the cylinder. As seen in Fig. 5 biodiesel-diesel blends gave higher thermal efficiency than diesel fuel, nearly all engine speed. This means that the engine converts the fuel energy to more effective power when operated with biodiesel-diesel blends. The oxygen content of blend fuels improve combustion phase and hence more fuel energy can be converted to power. Also, good lubricity property of the biodiesel affects the thermal efficiency positively. On average, the thermal efficiency of the engine by using diesel, B10, B20 and B50 were determined as 37.57%, 38.95%, 38.19% and 38.22%, respectively. Maximum thermal efficiency is obtained by B10 because that positive effect of the oxygen content and the negative effect of the high viscosity of the biodiesel result in an optimum biodiesel-diesel blend ratio, namely B10. By increasing the biodiesel percentage, the negative effect of the high viscosity of the biodiesel became more dominant than the positive effect of the oxygen content and good lubricity property of the biodiesel. As a result, at high biodiesel ratios, the thermal efficiency of the engine decreases.

Average exhaust emissions for test fuels are shown in Fig. 6-Fig. 10. Emissions emitted from the compression ignition engines are mostly dependent on air-fuel ratio, fuel type, combustion chamber design, the rate of atomization, start of injection timing, engine load and speed [12]. The variation of CO and HC emissions for test fuel are presented in Fig. 6 and Fig. 7, respectively. Not only CO and HC emissions have a serious impact on the environment and human health, but also, they represent lost chemical energy. CO emissions for B10 and B50 are 3.09% and 21.69% lower than diesel, respectively, but CO emission for B20 is 1.4% higher when compared to diesel fuel. As seen in Fig. 7, HC emissions for blend fuels are higher than diesel fuel. Average HC emission for diesel, B10, B20 and B50 were determined as 6.4, 9.7, 15.4, 16.6 ppm, respectively. It is estimated that higher viscosity and fuel consumption of the blend fuels result in more HC emission than diesel fuel operation. Additionally, biodiesel consist of different components which have a different boiling point and these components cannot evaporate and burn fully. Hence, more HC emissions may be emitted from the engine when using biodiesel-diesel blends.

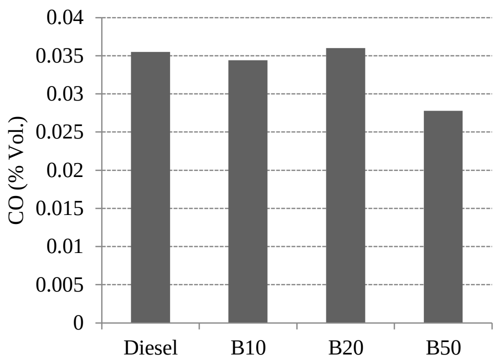

Fig. 6. Comparison of the CO emissions for test fuels.

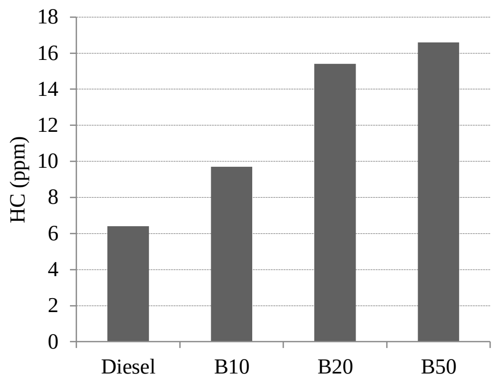

Fig. 7. Comparison of the HC emissions for test fuels.

Fig. 8 shows the NO_x emissions of the test fuels. As seen in the figure, blend fuels emitted more NO_x emissions when compared to diesel fuel. It is calculated that NO_x emissions of B10, B20 and B50 are 16.25, 9.48 and 38.84% higher than diesel fuels, respectively. The reasons for the higher NO_x

emissions for blend fuels may be oxygen content of the biodiesel. Additionally, higher viscosity, higher density and lower compressibility of the biodiesel cause an advance start of injection timing which increases NO_x emissions [4]. Therefore, by advancing the start of injection timing through the use of blend fuels could produce more NO_x emission than diesel fuel. Variation of the CO_2 emissions for test fuels is shown in Fig. 9. CO_2 emission is a product of the complete combustion but it is a greenhouse gas and has been limited in many countries. The main ways to reduce CO_2 emission are the reduction of the fuel consumption and the use biofuels instead of fossil fuels. As depicted in Fig. 9 CO_2 emissions for blend fuels are higher than diesel fuel. Average CO_2 emissions for diesel, B10, B20 and B50 were determined as 7.41, 7.96, 7.96 and 8.14% (vol.), respectively. The higher CO_2 emissions for blend fuels can be attributed to their higher carbon contents and higher fuel consumptions compared to diesel fuel.

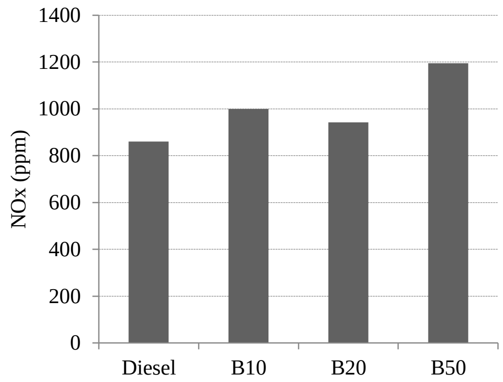

Fig. 8. Comparison of the NO_x emissions for test fuels.

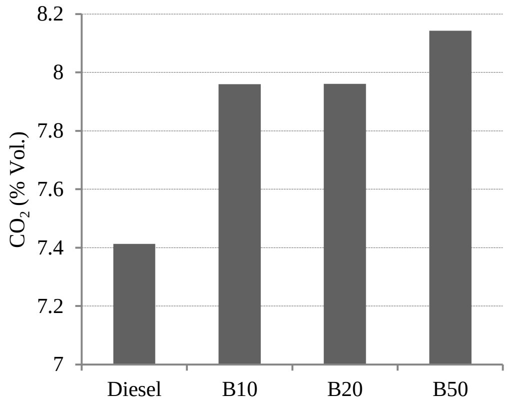

Fig. 9. Comparison of the CO_2 emissions for test fuels.

Furthermore, the higher CO_2 emissions for blend fuels may originate from their oxygen contents which improve the combustion quality and hence cause an increase in CO_2 emissions [5]. In fact, as a part of the carbon cycle, biodiesel does not contribute to the greenhouse effect [13]. When using the biodiesel-diesel blend as fuel the greenhouse effect can be reduced. Hence, the high CO_2 emissions for biodiesel-diesel fuel blends should not be evaluated as a disadvantage of them. O_2 emission for test fuels is shown in Fig. 10. As seen in the figure blend fuels gave less O_2 emission than diesel fuel. Average, O_2 emission for diesel, B10, B20 and B50 was determined as 9.56, 8.60, 7.53 and 7.35 % (vol.), respectively. In spite of oxygen content of blend fuels, the engine emits less O_2 emission by using them. The reasons of this may be more carbon atom converted to CO_2 with blend fuels. The result is compatible with variation of CO_2 emissions.

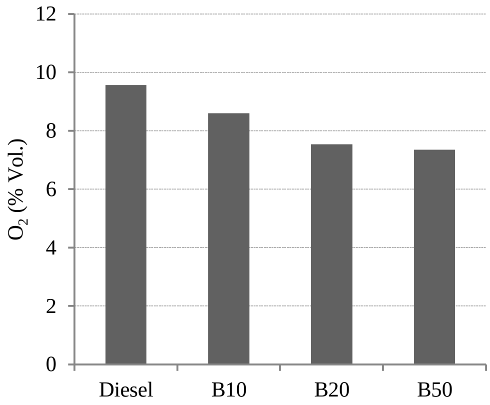

Fig. 10. Comparison of the O_2 emissions for test fuels.

IV. Conclusions

In this study, performance and emissions of a single cylinder, direct injection diesel engine fueled with corn oil methyl ester-diesel fuel blends were investigated experimentally and the results were compared for each test fuel usage. The obtained results show that B20 and B50 gave lower engine torque and higher brake specific fuel consumption than diesel fuel. However, it is determined that by using B10 there were not big differences between engine torque and brake specific fuel consumption when compared to diesel fuel. Blend fuels gave higher brake thermal efficiency than diesel fuel and the maximum average brake thermal efficiency obtained with B10 as 38.95%. Comparisons of the emissions demonstrated that blend fuels emitted more HC, NO_x and CO_2 emissions when compared to diesel fuel. But it is observed that lower CO and O_2 emissions for blend fuels, generally. Consequently, B10 blend fuel can be substituted for diesel fuel in the tested diesel engine without any engine modification. Moreover, slight higher emissions for B10 are negligible or they can be reduced by after -treatment system.

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