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The influence of canola oil biodiesel on performance, combustion characteristics and exhaust emissions of a small diesel engine

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ABSTRACT

In this work, the influence of canola oil biodiesel addition to eurodiesel was evaluated on combustion, performance characteristics and exhaust emissions of a single cylinder diesel engine. In the experiments, fuel mixtures obtained by adding 10%, 20% and 50% canola oil biodiesel (named COB10, COB20 and COB50 respectively) to eurodiesel fuel (COB0) were used. The test engine was loaded at full load with electrical dynamometer and data was recorded between 1500 rpm and 3000 rpm at 500 rpm intervals. The result show that addition of biodiesel to eurodiesel reduced cylinder pressure, engine torque and BTE while increased BSFC. Ignition delay decreased slightly with the addition of biodiesel. NO_x emission and smoke density were decreased as the biodiesel content increase in the fuel blends.

Keywords: Canola oil biodiesel, performance, combustion, exhaust emissions

1. INTRODUCTION

Biodiesel is a renewable resource and a good alternative to diesel fuel. Waste oils, used cooking oils, vegetable oils and animal fats and microalgae can be used as biodiesel raw materials. HC, CO, CO_2 and PM emissions except NO_x emissions are less emitted with the use of biodiesel in diesel engines. The lubricant feature extends engine life without any additional lubricant additives. It is also more economical as it is derived from local and renewable sources, so that it is a solution for energy demand [1]. The use of 100% biodiesel in diesel engines is not recommended because of the high density and viscosity of biodiesel which causing injector and fuel line problems [2]. For these reasons, biodiesel is usually blended with diesel fuel at various proportions without any engine modifications [3].

Canola seeds are very suitable for biodiesel production with very high oil content (approximately 40-45%) from other oily seeds [4]. Canola biodiesel is well mixed with diesel fuel because the density difference between the canola oil biodiesel and diesel fuel (canola 883.5 kg/m^3, diesel fuel 831.5 kg/m^3) is not as large as the viscosity difference (canola 4.32 mm^2/s, diesel fuel 2.6 mm^2/s) [5]. One of the advantages of biodiesel compared to diesel fuel is oxygen content. Canola biodiesel has approximately %10 oxygen content. The high oxygen content cause the reduction in the ignition delay and exhaust emissions (PM, CO and HC) and improve the combustion [6].

There are many studies in the literature using edible vegetable oil biodiesel in diesel engines. Can et al. [7] studied the effects of canola biodiesel blends in different mixing ratios at different loads in a single-cylinder diesel engine. As a result, they reported that the canola biodiesel blends caused a shorter ignition delay for all engine loads because of the earlier combustion timing. When the ratio of canola biodiesel increased, maximum in-cylinder

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pressures, maximum heat release rate and brake thermal efficiency (BTE) decreased while brake specific fuel consumption (BSFC) increased. In addition, it was stated that canola biodiesel mixtures caused a decrease in smoke, HC and CO emissions and increased NO_x and CO_2 emissions.

Ozsezen et al. [8] investigated the effect of injection characteristics, performance and combustion behaviors of a direct injection diesel engine when it was operated with palm oil and canola oil methyl esters under full load. The results indicated that the brake power reduced and the BSFC increased when the test engine was operated with both methyl ester blends. Also, methyl esters caused reductions in CO, HC, CO_2 and smoke emissions. However, both methyl esters caused more NO_x emissions. Zhang and Van Gerpen [9] examined the of soybean oil methyl esters blends in aturbocharged diesel engine. The results showed that the methyl ester blends caused similar combustion characteristics as diesel fuel.

Many studies were reported in the literature on engine performance and emission characteristics of various edible vegetable oil biodiesel blends. However, the studies on the analysis of combustion are limited. The main objective of this study is to evaluate the effects of canola oil biodiesel blends on combustion, performance, and emissions.

2. MATERIALS AND METHODS

The fuel mixtures obtained by adding 10%, 20% and 50% canola oil biodiesel (named COB10, COB20 and COB50 respectively) to eurodiesel fuel (COB0) were used in the experiments. Table 1 shows some basic properties of the test fuels. The experimental set-up is shown in Figure 1.

Table 1. Important features of the test fuels.

Properties	Diesel	COB10	COB20	COB50
Density (kg/m^3)	831.5	836.7	841.9	857.5
Kinematics Viscosity (mm^2/s)	2.40	2.60	2.79	3.36
Lower heating value (MJ/kg)	43.20	42.73	42.26	40.85
Cetane Number	58.8	58.3	57.9	56.5

The engine was connected to a 15 kW Kemsan brand DC dynamometer. The test engine was loaded at full load and data was recorded between 1500 rpm and 3000 rpm at 500 rpm intervals. Torque measurement was made by a flange system, consisting of the torque measuring unit KiTorq rotor Type 4550A and the torque evaluation unit KiTorq stator Type 4541A.In order to measure the cylinder pressure, Kistler 6052c having a piezoelectric crystal which achieves high sensitivity has been used. The Kistler 4065B compact high pressure sensor is attached on the fuel line to detect the start of injection. Kistler 2614B type optical crank angle encoder was used to calculate the crank angle and TDC data (a resolution of 720 x 0.1° crank angle degree (CAD)). Table 2 shows the specification of the Lombardini brand 15 LD 350 model diesel engine used in the experiments.

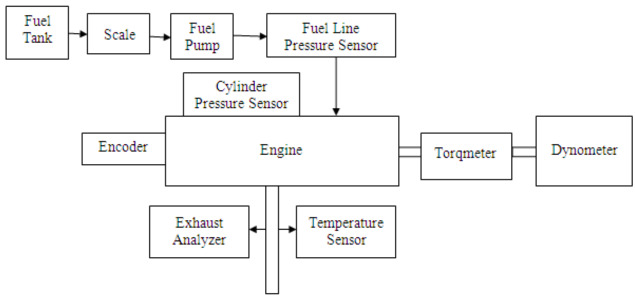

Figure 1. Schematic representation of the experimental setup

Table 2. The specification of the Lombardini 15 LD 350

Items	Specifications
Cylinder	1
Cooling	Air cooled
Maximum torque	16.6 Nm/2400 rpm
Compression ratio	20.3/1
Displacement	349 cm^3
Bore	82 mm
Stroke	66 mm
Nozzle opening pressure	207 bar
Injection pump type	QLC type

All data excluding emission values were collected with KiBox To Go data acquisition system and evaluated with KiBox Cockpit software. Mobydick 5000 was used for obtain smoke density and NO_x values. The basic feature of the Mobydick 5000 is shown in Table 3. Before collecting data for each test the engine was run for 10 minutes until it reaches operating temperature. A scale and stopwatch were used to measure fuel consumption.

Table 3. The basic feature of the exhaust analyzer

Emission	Unit	Range	Accuracy
Smoke Density	m^{-1}	0-20	0.01
NOx	ppm	0-5000	1

The following formulas were used in the calculations:

The Engine brake power (kW):

$$P_b = \frac{M.n}{9459} \quad (1)$$

The brake specific fuel consumption (g/kWh):

$$BSFC = \frac{m_{\dot{f}uel}.3600}{P_b} \quad (2)$$

The Brake Thermal Efficiency (%):

$$BTE = \frac{P_b}{m_{\dot{f}uel}.LHV}.100 \quad (3)$$

The Rate of Heat Release (RoHR) (J/CAD):

$$RoRH = \frac{k}{k-1}P\frac{dV}{d\theta} + \frac{1}{1-k}V\frac{dP}{d\theta} \quad (4)$$

5% of total heat release and 90% of total heat release were taken as the start of combustion (SoC) and the end of combustion (EoC), respectively. Duration of combustion (DoC) is difference between SoC and EoC. The start of injection (SoI) is the crank angle corresponds to at which fuel line pressure reaches nozzle opening pressure (207 bar). Ignition delay (ID) is the difference between SoI and SoC.

3. RESULTS AND DISCUSSION

Figure 2 shows the torquevariation of test fuels with respect to different engine speed. Unlike to gasoline engines, torque is less dependent on engine speed in diesel engines. Due to the increase in the volumetric efficiency and the decrease in the heat losses with gas leaks per stroke, the torque has increased upto 2500 rpm for all fuel. The reduction of torque at 3000 rpm depends on the decrease in volumetric efficiency and the increase of friction losses. Due to the low heating value of the biodiesel, engine torque was decreased as the amount of the biodiesel in the blend increase. Also, the high viscosity and density of biodiesel reduce the atomization efficiency, therefore engine torque decrease [10].

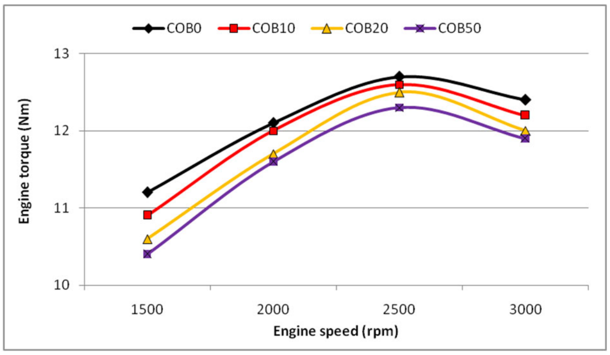

Figure 2. Engine torque graphs of the test fuels

The BSFC of test fuels are shown in Figure3. The decrease in BSFC upto 2500 rpm in all test fuels is thought to be due to increase in volumetric efficiency and decrease in gas leakage and heat loss. The most important factor affecting BSFC is heating value [11]. Low heating value of canola biodiesel increased BSFC as seen in Figure3.

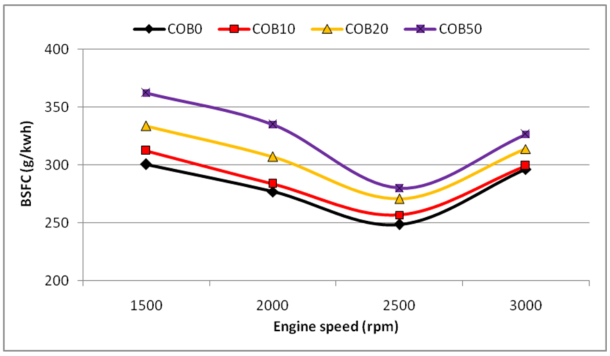

Figure 3. BSFC graphs of the test fuels

BTE is the ratio of the effective power measured at the engine output to the power to be obtained by the complete combustion of the fuel. It provides information about combustion efficiency. BTE changes of the test fuels according to different engine speed at full load are shown in Figure 4. BTE value was decreased with addition of biodiesel because biodiesel has low heating value. In spite of the high oxygen content of COB, BTE has decreased due to the high density and high viscosity of biodiesel, which worsens the fuel atomization [12]. A similar trend was observed at BTE for all test fuels at all engine speed. BTEs increased with engine speed increase, reached peak values at 2500 rpm then slightly decreased at

3000 rpm as shown in Figure 4. The BTE differences at high engine speeds were observed as smaller when compared with lower engine speeds.

Physical and chemical fuel properties such as density, viscosity, cetane number and heating value affect the combustion characteristics, engine performance and emissions. By evaluating the cylinder pressure, RoHR and ID, the combustion performance of different fuels can be compared [13].

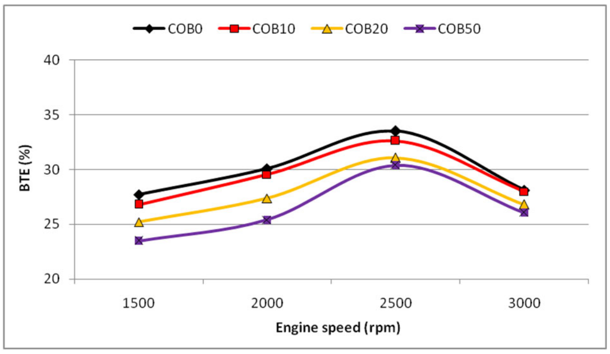

Figure 4. BTE graphs of the test fuels

The cylinder gas pressure and RoHR for diesel fuel and blends are presented in Figure 5. Because of the high heating value of diesel fuel, cylinder pressures are higher than biodiesel blends for all engine speeds as seen in Figure 5. The torque curves in Figure 2 confirm this. It is seen that the maximum pressure values of diesel fuel are higher than around 1-2 bar compared to the biodiesel blends. This is related to the higher heating value, but also to the longer ignition delay time of diesel fuel. As it can be seen more clearly in the RoHR curves, the rapid combustion of fuel accumulated in the cylinder during the ignition delay, which is called the pre-mixed combustion phase, causes the higher in-cylinder pressure and heat.

Figure 6 shows the change of SoI, SoC, and EoC of the canola oil biodiesel at four different engine revolutions. With the increase in engine speed, the premixed combustion phase decreased and the diffusion combustion duration increased because of the moving of SoC toward TDC, which caused the decrease in the maximum pressure values. In spite of similar RoHR values, the torque values at 3000 rpm are lower than those of 2500 rpm, due to increased friction losses.

In the engines with mechanical fuel pumps, the fuel line pressure increases due to the low compressibility, high density and high viscosity of biodiesel blends and thus the injector opens earlier [14]. Although the SoC for all engine speed is quite close to each other, SoC of COB50 is about 0.3-0.5 CAD earlier in comparison to the diesel fuel as seen in Figure 7.

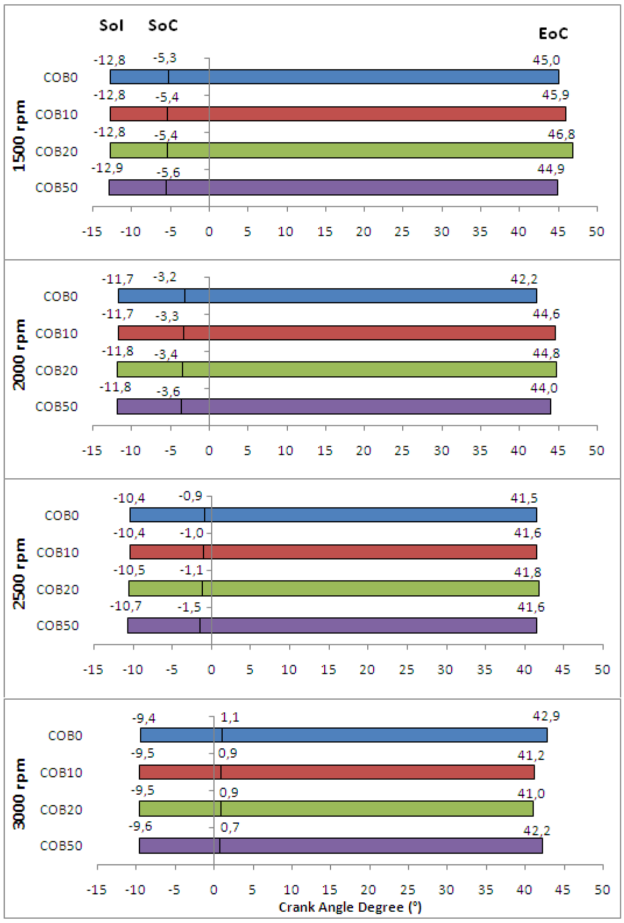

Figure 6. Change of SoI, SoC and EoC of the test fuels

The ignition delay is an important determinant for the combustion characteristics. Oxygen content, atomization of the fuel, cylinder pressure and especially cetane number influence the ignition delay. Since ID is the time between SoI and SoC, all the parameters affecting them also affect the ID. The addition of biodiesel to the eurodiesel reduced the ID slightly as shown in Figure7. Although the cetane number of diesel is slightly higher than those of the blends, the oxygen content of biodiesel is effective in reducing the ID. In addition, the small amount of aromatic content of biodiesel is one of the factors that reduce the ID [15].

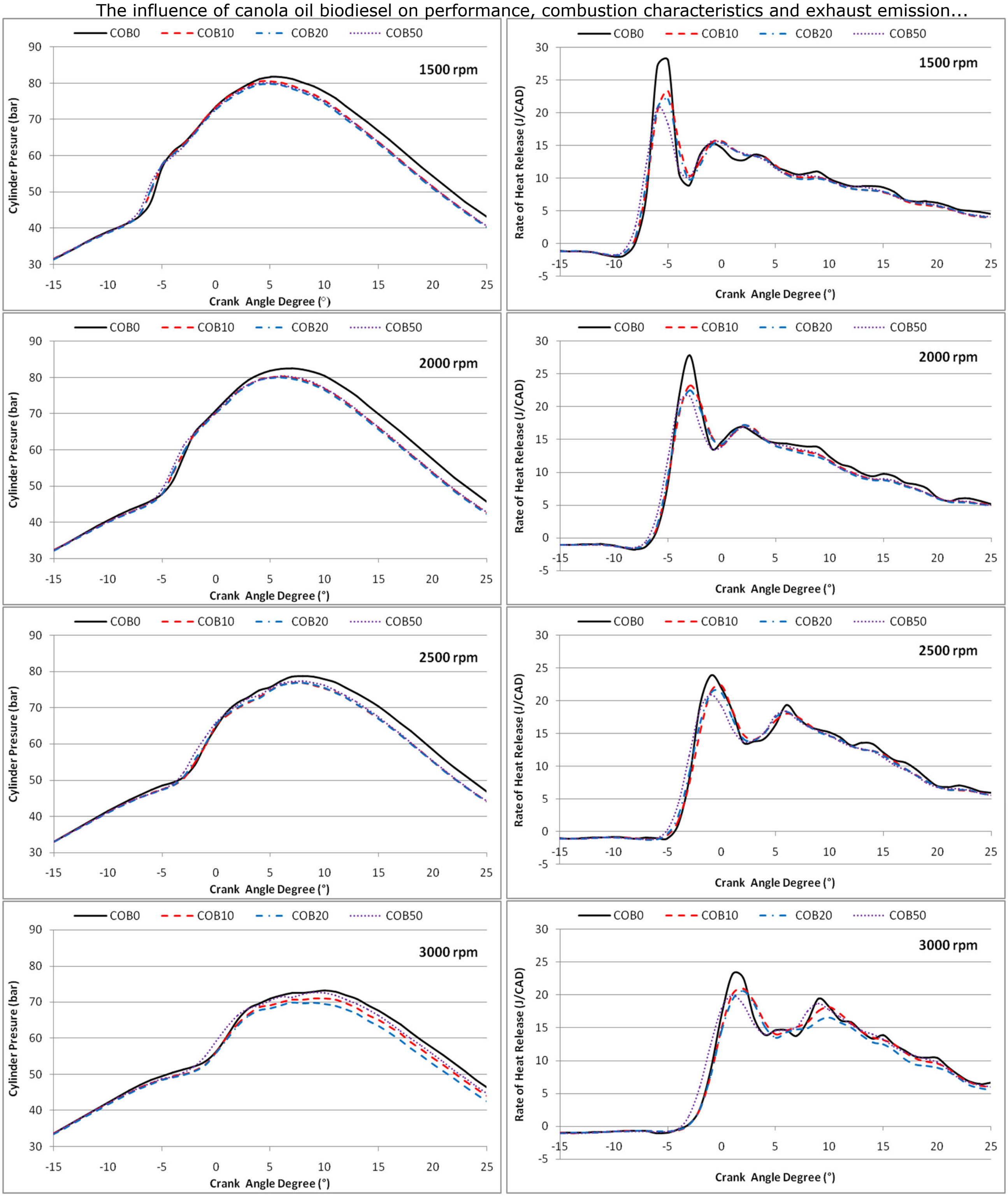

Figure 5. Cylinder pressure and RoHR graphs of the test fuels.

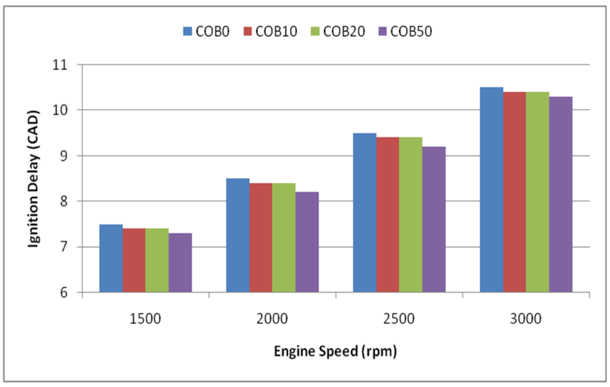

Figure 7. ID graphs of the test fuels

Since the fuel injected into the cylinder is exposed to higher temperatures and pressures as the SoI is late, the ignition takes less time. However, with increasing engine speed, this time corresponds to a larger crank angle [16].

The change in exhaust temperature is shown in Figure 8. As the engine speed increases, frequency of combustion increases in unit time, so that the exhaust temperature increases. The increase in the diffusion combustion phase is also effective in increasing the exhaust temperature as shown in RoHR graphics. The increase in the amount of biodiesel in the blends for each engine speed reduces the exhaust gas temperature.

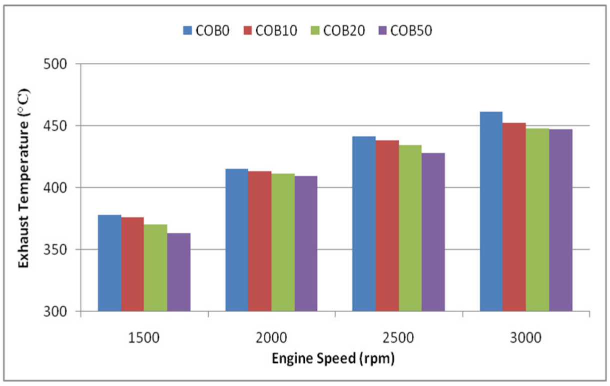

Figure 8. Exhaust temperaturegraphs of the test fuels

The change in NO_x emissions is shown in Figure 9. As defined in Zeldovich Mechanism, the oxygen and nitrogen in the air react with each other due to the high temperature in combustion chamber. Thus, NO_x emerge as products. The formation of NO_x depends on ignition delay, oxygen content of fuel and combustion temperature [17].

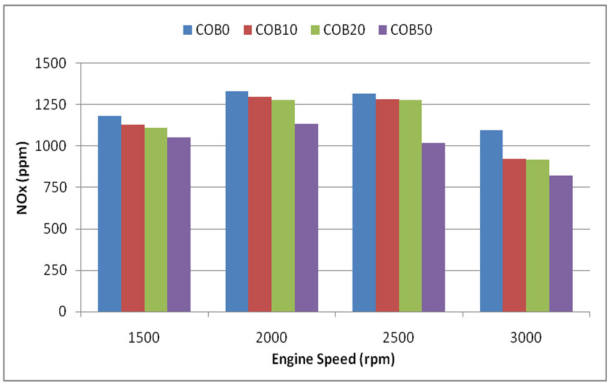

Figure 9. NO_x graphs of the test fuels

As seen in Figure 9, the concentration of NO_x was decreased as the biodiesel content increase in the fuel blends, because the low heating value of biodiesel causes in lower cylinder pressure and temperatures.

Smoke density is the coefficient of light absorption of the exhaust emission gases released by the engine. It increases with the increase of particles formed by unburned carbon atoms. Smoke density depends on the temperature of cylinder, the amount of oxygen and soot particle residence time in the combustion chamber [18]. The change of smoke density of test fuels according to engine speed is shown in Figure 10. The addition of COB to euro diesel reduced the smoke density. Smoke density of the test fuels was lower at 1500 rpm but increased at 2000 and 2500 rpm and dropped again at 3000 rpm. As seen in Figure 10, the diesel fuel has highest smoke density at all engine speeds. COB10 comes after diesel fuel and is slightly lower than those of diesel fuel. Approximately 40% reduction was observed in COB50 according to diesel fuel for all engine speeds. The low C/H ratio and low oxygen content of canola oil biodiesel is thought to have an effect on reducing smoke density.

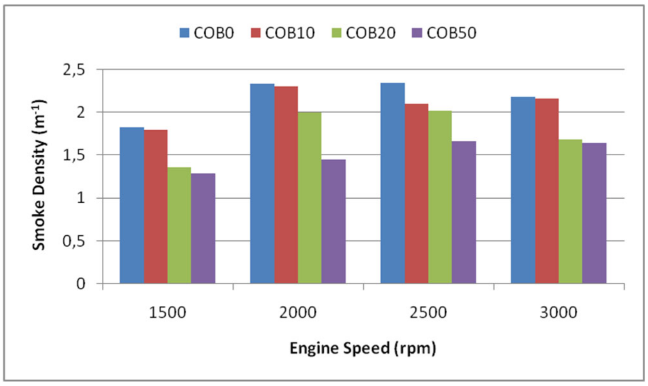

Figure 10. Smoke density graphs of the test fuels

4. CONCLUSIONS

In this study, the influence of canola oil biodiesel addition to eurodiesel was evaluated on combustion, emissions and performance characteristics of a single cylinder diesel engine at full load. In the light of the results, the following conclusions were obtained:

1. With the increase of the biodiesel in the fuel blends, engine torque decreased and BSFC increased due to the low heating value of the biodiesel.
2. Despite the high oxygen content of biodiesel, BTE decreased because of the high density and viscosity of biodiesel, which worsens fuel atomization.
3. The cylinder pressures of the diesel fuel are higher than those of the biodiesel blends for all engine speeds because of the high thermal value of diesel fuel.

4. The maximum cylinder pressure values of diesel fuel are higher than around 1-2 bar compared to the biodiesel blends.
5. The addition of COB to the eurodiesel reduced the ID slightly.
6. Because the low heating value of biodiesel causes lower cylinder pressure and temperatures, the NO_x emissions decreased with the increase the biodiesel content in the fuel blends.
7. The addition of COB to euro diesel reduced the smoke density.

REFERENCES

[1] H.M. Mahmudul, F.Y. Hagos, R. Mamat, A.A. Adam, W.F.W. Ishak and R. Alenezi, "Production, characterization and performance of biodiesel as an alternative fuel in diesel engines–A review," *Renewable and Sustainable Energy Reviews*, vol. *72*, pp. 497–509, 2017.

[2] Y.C. Sharma, B. Singh and S.N. Upadhyay, "Advancements in Development and Characterization of Biodiesel: A Review," *Fuel*, vol 87, pp. 2355–2373, 2008.

[3] G. Dwivedi, S. Jain and M.P. Sharma, "Diesel engine performance and emission analysis using biodiesel from various oil sources—Review," *J. Mater. Environ. Sci.*, vol. 4, pp. 434–447, 2013.

[4] D.K. Yadava, S. Vasudev, N. Singh, T. Mohapatra, and K.V. Prabhu, "Breeding Major Oil Crops: Present Status and Future Research Needs. In Technological Innovations in Major World Oil Crops," Volume 1: Breeding; Springer: New York, NY, USA, 2012; Chapter 2; Volume XIII, 405p, ISBN 978-1-4614-0355-5.

[5] S.K. Yoon, M.S. Kim, H.J. Kim, and N.J. Choi, "Effects of canola oil biodiesel fuel blends on combustion, performance, and emissions reduction in a common rail diesel engine," *Energies*, vol. 7, pp. 8132–8149, 2014.

[6] D. Singh, K.S. Subramanian, M. Juneja, K. Singh and S. Singh, "Investigating the effect of fuel cetane number, oxygen content, fuel density, and engine operating variables on NO_x emissions of a heavy duty diesel engine," *Environ. Prog. Sustain. Energy*, vol. 36, pp. 214–221, 2017.

[7] Ö. Can, E. Öztürk and H. S. Yücesu, "Combustion and exhaust emissions of canola biodiesel blends in a single cylinder DI diesel engine," *Renewable Energy,* vol. 109, pp. 73–82, 2017.

[8] A.N. Ozsezen, and M. Canakci, "Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters," *Energy Conversion and Management*, vol. 52, no 1, pp. 108–116, 2011.

[9] Y. Zhang and J.H. Van Gerpen, "Combustion Analysis of Esters of Soybean Oil in a Diesel Engine," *SAE paper* 960765.

[10] A. Keskin, "Experimental investigation of the effect of cottonseed oil biodiesel eurodiesel mixtures on combustion, performance and emissions at full load," *Afyon Kocatepe University Journal of Science and Engineering*, vol. 17, pp. 797–809, 2017.

[11] M. Şen, A.O. Emiroğlu and A. Keskin, "Production of Biodiesel from Broiler Chicken Rendering Fat and Investigation of Its Effects on Combustion, Performance, and Emissions of a Diesel Engine," *Energy & Fuels*, vol. 32, no 4, pp. 5209–5217, 2018.

[12] M. Mohamed Musthafa, S.P. Sivapirakasam and M. Udayakumar, "Comparative studies on fly ash coated low heat rejection diesel engine on performance and emission characteristics fueled by rice bran and pongamia methyl ester and their blend with diesel," *Energy*, vol. 36, no 5, pp. 2343–2351, 2011.

[13] A. O. Emiroğlu and M. Şen, "Combustion, performance and exhaust emission characterizations of a diesel engine operating with a ternary blend (alcohol-biodiesel-diesel fuel)," *Applied Thermal Engineering,* vol. 133, pp. 371–380, 2018.

[14] C. Sayin, M. Gumus, and M. Canakci, "Effect of fuel injection pressure on the injection, combustion and performance characteristics of a DI diesel engine fueled with canola oil methyl esters-diesel fuel blends," *Biomass and Bioenergy*, vol. 46 pp. 435–446, 2012.

[15] A.N. Ozsezen, M. Canakci, A. Turkcan and C. Sayin, "Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters," *Fuel*, vol. 88, no 4, pp. 629-636, 2009.

[16] H. An, W.M. Yang, S.K. Chou, S. K. and K.J. Chua, "Combustion and emissions characteristics of diesel engine fueled by biodiesel at partial load conditions," *Appl. Energy*, vol. 99, pp. 363−371, 2012.

[17] A.O. Emiroğlu, A. Keskin, and M. Şen, "Experimental investigation of the effects of turkey rendering fat biodiesel on combustion, performance and exhaust emissions of a diesel engine," *Fuel*, vol. 216, pp. 266–273, 2018.

[18] İ. Çelikten, and M.A. Arslan, "Investigation of Diesel Fuel, Rape Oil and Soybean Oil Methyl Esters Effects on a Direct Injection Diesel Engine Performance and Emissions," *Journal of The Fac. of Eng. and Arc. of Gazi University*, vol. 23, no 4, pp. 829–836, 2008.