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**Academic @ Paper**
ISSN 2146-9067
International Journal of Automotive Engineering and Technologies
Vol. 5, Issue 4, pp. 155 – 167, 2016

**International Journal of Automotive Engineering and Technologies**
http://www.academicpaper.org/index.php/IJAET

**Original Research Article**

# Comparison of the Effects of Animal and Vegetable Based Biodiesel in the Bioethanol-Diesel Blend on the Combustion and Emission Characteristics of a Common Rail Diesel Engine

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Received 14 July 2016 Accepted 22 December 2016

## Abstract

The usage of animal biodiesel (AB) was derived from waste fleshing oil, and vegetable biodiesel (VB) was produced from safflower-canola oil mixture in the bioethanol-diesel fuel blend have been investigated to find out the effects of biodiesel content and type on the combustion and emission parameters of a multi cylinder common rail diesel engine. The test fuels were determined as pure fossil diesel fuel (DF), bioethanol-diesel blend with 15% of bioethanol (E15) by mass and three bioethanol-diesel-biodiesel blends prepared for AB and VB that were mixed with different ratios. Biodiesel ratios varied at %5, %10 and %20 by mass in the bioethanol-diesel-biodiesel blends, while bioethanol-diesel concentration was maintained constant. Engine tests were conducted at constant engine speed and four different engine loads. The results of this study showed that maximum cylinder gas pressures ($P_{max}$) of the DF were 2.42 - 4.25 % higher than those of test blends at low and medium engine loads, while $P_{max}$ of the DF was measured maximum 1.58 % lower than those of biodiesel-bioethanol-diesel blends at high engine load. Brake specific fuel consumption (BSFC) of the DF was calculated 5.55 - 7.77 % lower than those of test blends. Oxides of nitrogen ($NO_x$) emissions of the both types of biodiesel blends were measured higher, while smoke and total hydrocarbon (THC) emissions of these blends were measured lower when compared with DF.

**Keywords:** Animal Fat Biodiesel, Vegetable Oil Biodiesel, Bioethanol, Combustion, Emissions, Diesel Engine

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## 1. Introduction

Increasing fuel conversion efficiency and reducing exhaust gas emissions are the major issues for the engine researchers due to the rapidly increasing energy consumption and tightening emission regulations in engine development. Therefore, European Parliament Members approved national action plans relating with share of energy from renewable sources in the transport sector which must be at least 10 % of final energy consumption in the sector by 2020. In this sense, a great number of researches have been conducted by using oxygenated fuels to increase fuel conversion efficiency and reduce engine exhaust emissions, simultaneously. The most widely used oxygenated fuels are biodiesel and ethanol. Blending these fuels with conventional diesel fuel have been evaluated as potential sources of renewable fuels, since ethanol can be derived from agricultural wastes and biodiesel can be produced from wastes of the vegetable oils or animal fats.

Ethanol has higher oxygen content, lower carbon to hydrogen (C/H) ratio, density, viscosity and boiling temperature than that of conventional diesel fuel. Although addition of ethanol to diesel fuel affects these fuel properties of the neat diesel fuel, ethanol-diesel fuel blends can be mixed in one phase at ambient temperature and also can directly be used without any modification of the diesel engines [1-4]. There are many numbers of experimental investigations relating with replacement of diesel fuel with these blends that could enhance complete combustion, improve volatility and decrease smoke and particulate matter (PM) emissions due to higher oxygen content, lower C/H ratio and boiling temperature when compared to neat diesel fuel [5]. The atomization and spray characteristics in the combustion chamber can be improved due to lower viscosity of the blend and also they significantly influence the evaporation characteristic time. This leads to provide homogeneous charge and clear combustion process; therefore it can decrease PM, THC and carbon monoxide (CO) emissions by using ethanol-diesel blends [6, 7]. Moreover, $NO_X$ emissions can be reduced or surpassed by using ethanol-diesel blends according to the engine operating conditions.

On the other side, some of the major fuel properties such as cetane number, energy content, viscosity and lubricity of the diesel fuel are reduced by adding ethanol to the diesel fuel [8], therefore some significant problems can be observed in terms of combustion characteristics, especially low load conditions [6], engine durability and reduction in lubricity [9]. In the literature, limited studies have been conducted to solve these problems by adding cetane improvers [10] and biodiesel to the ethanol-diesel blends [11-12]. Biodiesel can be mixed with alcohol and fossil diesel without any co-solvent and emulsifiers [6, 13, 14]. Shahir et al.[15-16] reported that the major fuel properties such as fuel miscibility, cetane number, viscosity and lubricity of the bioethanol/ethanol-diesel blends can be significantly improved by addition of biodiesel to these blends. Furthermore, reduction in engine wear and increase in lubricity can be provided by the addition of biodiesel to fossil diesel fuel [17, 18]. Armas et al. [11] has studied the effect of ethanol-biodiesel-diesel blend (7.7 vol % ethanol (E), 27.69 vol % biodiesel (B) and 69.61 vol % (fossil diesel)) and pure fossil diesel fuel on the common rail injection system components. They found out that the used test fuels showed similar effects on the surfaces of the pump elements (drive shaft, cam and piston) independently.

Park et al. [17] studied that the effects of vegetable based biodiesel content in the bioethanol-diesel blends the combustion and emission parameters of single cylinder diesel engine. They used biodiesel ratios varied at %5, %10 and %20 by volume in the bioethanol-diesel-biodiesel blends, while bioethanol concentration was maintained constant at %20 by volume. They observed that the ignition delay is shorter and the premixed combustion phasing advanced with the increase of biodiesel content in ternary blends, while there were not any differences between the maximum rate of heat release of the prepared blends. They calculated lower CO, and soot emissions by controlling injection timing and significant reduction in HC emissions, while slightly increase in NOx emissions with increasing biodiesel content. Guido et al. [12] compared bioethanol-vegetable based biodiesel-diesel blend (70%vol. of diesel, 20% vol. of ethanol and %10 vol. of Rapeseed Methyl Ester (RME)) with biodiesel-diesel blend (10% vol. of biodiesel and %90 vol. of diesel) in a Euro 5 diesel engine which controlled with closed loop combustion control system. They observed significant reduction in smoke and NOx emissions with adding bioethanol at partial load conditions, while there is no significant difference between test fuels with or without ethanol at full load conditions. The ethanol blends with diesel are critical for low load and speed conditions due to remain high unburned emissions. Beatrice et al. [18] observed that significant reduction in both HC and CO emissions and improving fuel conversion efficiency and $CO_2$ emissions by using optimized injection parameters, same engine and fuel blends as those used by Guido et al [12]. They found that NOx and PM emissions can be reachable to Euro 6 limit without usage of after-treatment systems. The longer ignition delay time and lower heat content of the ethanol can be controlled by closed loop combustion control system.

Alptekin et al. [19] investigated the effects of two different types of animal biodiesels are derived from fleshing oil and chicken fat in the bioethanol-diesel blends on the direct injection diesel engine over a wide range of load and speed conditions. Researchers found a decrease in the energy conversion efficiency of the composite fuel blends due to lower heating value when compared to the diesel. The maximum cylinder gas pressures of the bioethanol blends were obtained lower than that of pure diesel and biodiesel fuel. The start of combustion values retarded by usage of bioethanol blends. Moreover, bioethanol blends showed different trends in CO and NOx emissions with respect engine load. They observed that animal fat based biodiesel and bioethanol can be used as alternative oxygenated fuels in direct injection diesel engines. Venu and Madhavan [20] studied improving the performance of alcohol-biodiesel-diesel by usage of diethyl ether as ignition enhancer in the single cylinder diesel engine. They observed increase in combustion duration, cylinder pressure, bsfc, and decrease in NOx and smoke emissions with addition of diethyl in the alcohol-biodiesel-diesel blends due to improved fuel atomization and enhanced fuel spray characteristics. Parthasarathy et.al. [21] used vegetable based biodiesel in a single cylinder unmodified diesel engine. They prepared ethanol-biodiesel blends to reduce NOx emissions and injected hydrogen into the manifold due to clean burning characteristic of the hydrogen. The results showed that hydrogen and ethanol-biodiesel blends decreased bsfc, CO, NOx and smoke emissions.

As seen in the literature review, there are not enough studies about especially animal based biodiesel on the application of bioethanol-diesel blends in a common rail diesel engine. The purpose of this study, two different types of fuels one of which is animal based and the other is vegetable based biodiesels at different ratios were added to the bioethanol-diesel blends to investigate and to compare the effects of biodiesel content and type on the combustion and emissions parameters of a direct injection common rail diesel engine under different engine load conditions.

## 2. Experimental Setup and Procedure

In this study, a water-cooled, turbocharged, light duty, common rail direct injection diesel engine for passenger cars and also cargo was used. The engine specifications and hydraulic dynamometer were shown in Table 1, and schematic diagram of the engine test cell was shown in Fig.1. The test engine was coupled to a hydraulic dynamometer and K type thermocouples with a digital temperature indicator were used in measuring the intake air, exhaust gas, fuel, oil and cooling water inlet-outlet temperatures.

The cylinder gas pressure data was measured with a glow-plug with integrated AVL pressure sensor and analyzed by using IndiCom platform used for combustion analysis that combines the control of data acquisition with evaluation data of the cylinder gas pressure, crank angle and energizing injector's current. The exhaust emissions were measured by AVL SESAM FTIR emission device that includes a flame ionization detector (FID) and Fourier transform infrared spectroscopy (FTIR) analyzer. The specifications of the FTIR exhaust emission device were given in the Table 2. In this study total unburned hydrocarbon (THC) emission was measured by using FID, carbon monoxide (CO) and nitrogen oxides (NOx) emissions were measured by using FTIR analyzer, smoke was measured by BOSCH RTM 430 smoke meter.

Table 1. Specifications of the test engine and hydraulic dynamometer

| Engine | 1.9 JTD, Fiat Group Multijet |
|---|---|
| Type | Common rail direct injection turbo diesel, four stroke, water cooled |
| Number of Cylinder | 4 |
| Bore - Stroke | 82 mm – 90.4 mm |
| Compression Ratio | 18.45:1 |
| Injection System | Common Rail Direct Injection |
| Maximum power | 77 kW - 4000 rpm |
| Maximum brake torque | 205 Nm - 1750 rpm |
| Dynamometer | Hydraulic |
| Brake Model | BT-190 FR |
| Maximum power | 100 Kw |
| Maximum load | 750 Nm |
| Maximum speed | 6000 rpm |
| Load Measurement | Load Cell |

Table 2. Specifications of FTIR exhaust emission device

| Parameter | Unit | Accuracy |
|---|---|---|
| HC | ppm | < ± 2 of measured value<br>(10 – 100 % of measuring range)<br>or ≤ ± 1 % of full scale, whichever is smaller |
| CO | ppm | better than 2 % ± of measured value |
| CO2 | % | better than 2 % ± of measured value |
| NOx | ppm | better than 2 % ± of measured value |
| Measurements | | |
| Load Monitoring | Nm | ±2% |
| Speed measuring | rpm | ±1 |
| Fuel consumption (mass) | g | ±1 |
| Air consumption (volume) | m3 | ±3% |
| Temperature | °C | ±1 |

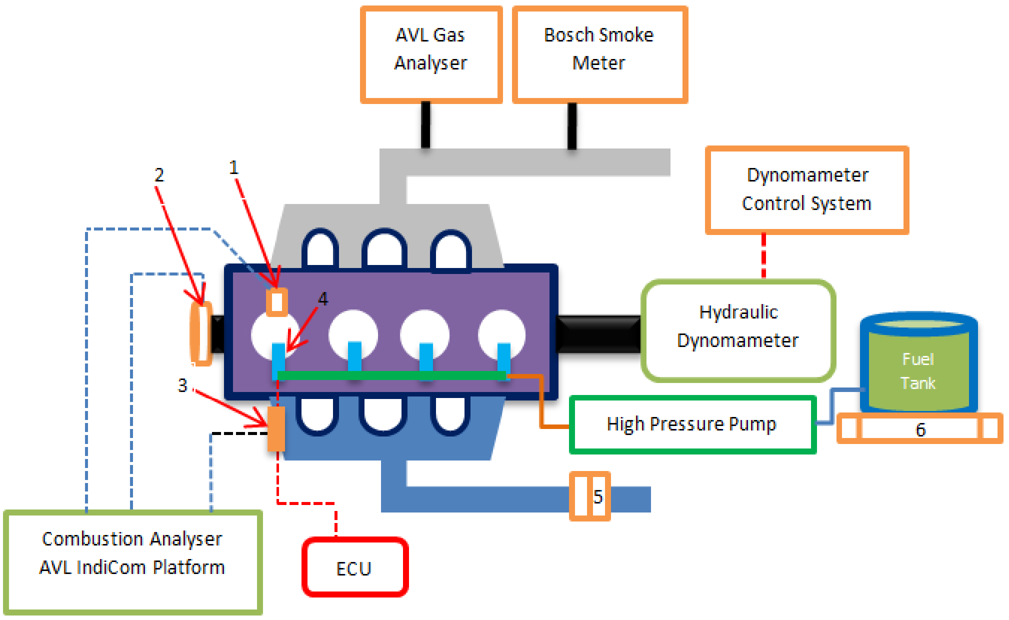

Fig.1. The schematic diagram of the experimental setup: (1) AVL Glow-plug pressure sensor; (2) AVL crank angle encoder; (3) Current probe; (4) Common rail injector; (5) Air flow meter; (6) Fuel mass meter.

In this study, the animal biodiesel (AB) was derived from waste fleshing oil, the vegetable biodiesel (VB) was produced from safflower-canola oil mixture, bioethanol obtained from Pankobirlik Bioethanol Manufacturing Plant (Konya, Turkey) was made of used wastes originated from sugar production process and DF was bought from a local petrol station. The fuel properties of pure diesel fuel (DF), bioethanol (BE), AB and VB were given in Tables 3.

Table 3. Fuel properties of the biodiesels, diesel fuel and bioethanol

| Property | Unit | DF | BE | AB | VB |
|---|---|---|---|---|---|
| Density (15°C) | $kg.m^{-3}$ | 829 | 793 | 876.7 | 883.6 |
| Viscosity (40°C) | $mm^2.s^{-1}$ | 3.0 | 1.2 | 4.7 | 4.3 |
| Flash Point | °C | 63 | - | 168 | 186 |
| Water Content | ppm | 20 | 163 | 410 | 240 |
| Acid Number | mg $KOH.g^{-1}$ | - | - | 0.28 | 0.28 |
| Monoglyceride | % (mass) | - | - | 0.06 | 0.49 |
| Diglyceride | % (mass) | - | - | 0.02 | 0.15 |
| Triglyceride | % (mass) | - | - | 0.20 | 0.01 |
| Free Glycerin | % (mass) | - | - | 0.01 | 0.001 |
| Total Glycerin | % (mass) | - | - | 0.05 | 0.15 |
| Copper Strip Corrosion (3 h, 50°C) | Degree of Corrosivity | No 1 | No 1 | No 1 | No 1 |
| Higher Heating Value | $MJ.kg^{-1}$ | 45.9 | 28.9 | 39.9 | 40.1 |
| Cetane Number | - | 56.8 | - | 58.8 | 53.0 |
| Methanol Content | % (mass) | - | 0.04 | 0.01 | 0 |
| Iodine Number | g $I.100g^{-1}$ | - | - | 53.6 | 112.8 |
| Sulfur Content | ppm | 8.7 | 1.8 | 138.1 | 3.2 |
| Cold Filter Plugging Point | °C | -15 | - | 10 | -9 |

The prepared test blends are diesel-bioethanol blends (15% mass of BE in diesel) indicated as (E15), diesel-bioethanol-animal biodiesel blends (15% mass of BE with 5, 10 and %20 mass of AB in diesel) indicated as E15AB5, E15AB10 and E15AB20, diesel-bioethanol-vegetable biodiesel blends (15% mass of BE with 5, 10 and %20 mass of VB in diesel) indicated as E15VB5, E15VB10 and E15VB20, respectively. During the observations there was no significant phase separation for first several days. However, after one week, there was a phase separation in the fuel blends especially containing ethanol. Therefore, the test fuels were prepared daily and they were mixed before the each test. The test fuels were characterized in the Alternative Fuels Research and Development Center in Kocaeli University (AFRDC), Marmara Research Center-The Scientific and Technological Research Council of Turkey (MRC-TUBITAK) and Pankobirlik Bioethanol Manufacturing Plant (PBMP). Four different engine loads and constant engine speed were selected for the engine tests. For this study, test conditions were determined as 40Nm for low load, 80 and 120 Nm for medium loads, and 160 Nm for high load. The maximum engine load 205 Nm, therefore the 160 Nm (about 80% percent of the maximum engine load) was determined as high load. All test fuels were tested at different engine conditions for three times and the average results were taken.

## 3. Results and Discussion

In this section, the combustion characteristics as cylinder gas pressure, rate of heat release (RHR), maximum cylinder gas pressure ($P_{max}$), maximum pressure rise rate (MPRR) and start of combustion (SOC), performance parameters as brake specific fuel consumption (BSFC) and the emission characteristics as $NO_X$, smoke, THC and CO were investigated for all test fuels. Moreover, the effects of the different type and amount of biodiesels in the bioethanol-diesel blend on combustion, performance and emissions characteristics at four different load conditions were discussed.

### 3.1. Combustion and performance characteristics

Cylinder gas pressure and rate of heat release for all test fuels are presented in Fig.2 to compare the effects of the AB blends (a) and VB blends (b) in the bioethanol-diesel blend. As seen clearly on the figure, the patterns of cylinder gas pressure have two peaks because electronic controlled diesel fuel injection system uses two stage (pre and main) fuel injection techniques in one engine cycle. The second peak of the cylinder gas pressures were observed lower than that of the first peaks at the low and medium loads. On the other hand, at high engine load conditions the second peak of the cylinder gas pressure for all test fuels was about 3.23-10.05 % higher than that of first peak due to higher amount of fuel injected for obtaining higher load from the engine. The cylinder gas pressure and rate of heat release for all test blends increased with engine load, while there is no significant difference among the test blends. It can be seen from the Fig.2 that combustion occurred early crank angle and combustion duration increased with increasing engine load for all test fuels. E15 in comparison with the other test fuels maximum HRR of the E15 blend decreased slightly at high engine load conditions due to higher latent of heat vaporization of ethanol. At high engine load condition, the maximum HRR values were obtained by using E15AB5 and E15AB20, E15VB5 and E15VB20. In addition, cylinder gas pressure patterns and heat release curves were observed very close to each other for AB and VB blends for all operating conditions although there were differences in the fuel properties of the AB and VB fuels.

In order to compare the effects of test fuels on the combustion characteristics as $P_{max}$, MPRR and SOC are plotted versus the operating conditions in the Fig.3. As seen in the figure (a) and (b) generally, $P_{max}$ of DF was observed about 2.42-4.25% higher than the other test fuels at low and medium loads, while $P_{max}$ of DF decreased at high engine load as compared to all test blends expect for E15VB10. The maximum $P_{max}$ was 93.71 bar by usage of E15VB5 in the VB blends, while the maximum $P_{max}$ was 94.12 bar by usage of E15AB5 in the AB blends. It can clearly be said that cylinder gas pressure can be increased by the addition of different type and ratios of biodiesel. The reason of this situation can be explained with increase in cetane number, oxygen content and density due to the addition of the biodiesel to the bioethanol-diesel blend, which could improve the combustion process.

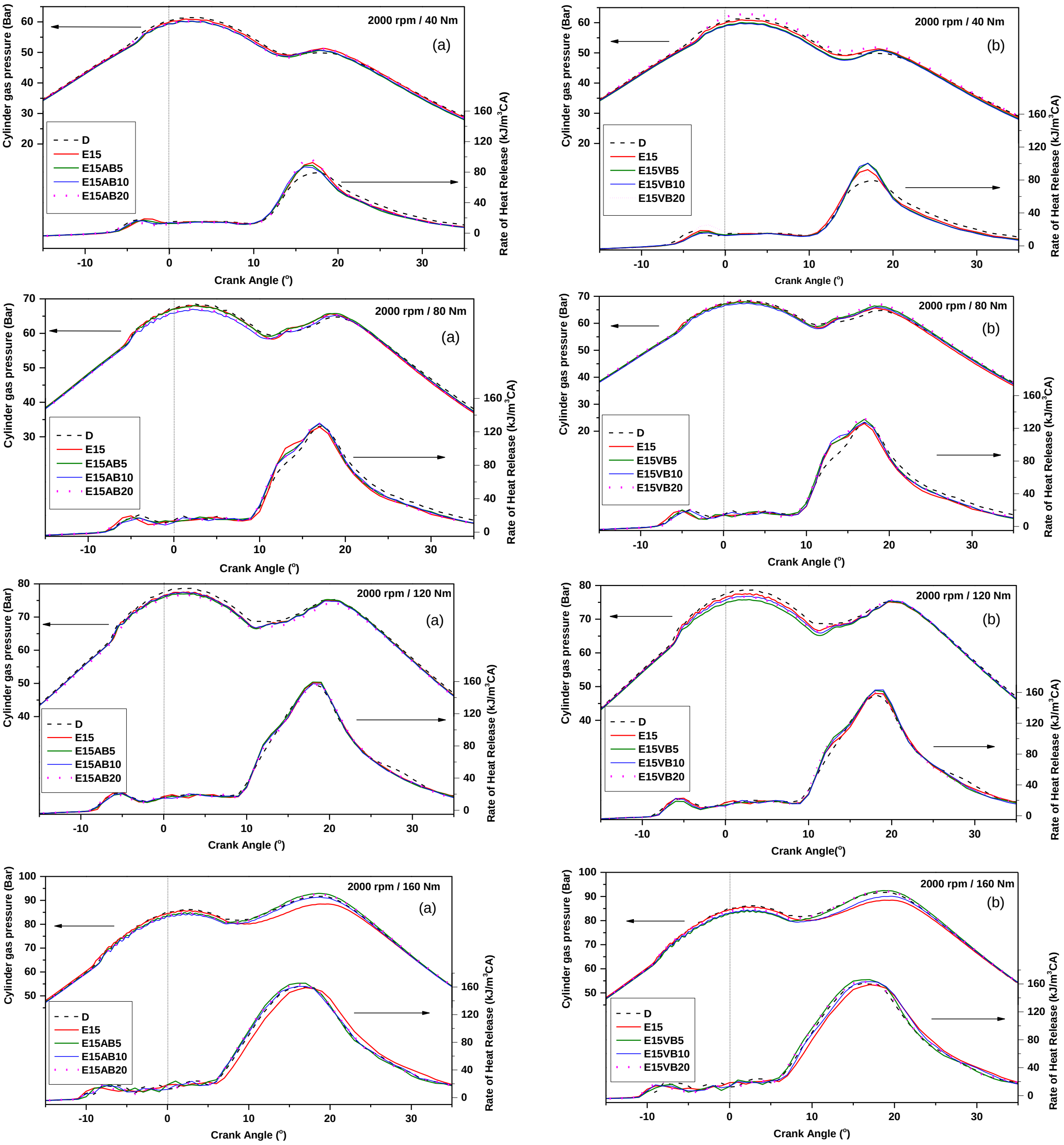

Fig. 2. Comparison of cylinder pressures and heat release rates

Fig.3 shows SOC versus test cases for both AB (a), VB (b) blends in the bioethanol-diesel blend, DF and E15. SOC results of the DF at medium and high load conditions advanced when compared E15, AB and VB blends. Simultaneously, the SOC results of the E15 retarded as compared with the other test fuels at high load conditions. It is known that major factor affecting SOC is cetane number. Addition of VB and AB in the bioethanol-diesel blend increase cetane number of the blend compared to bioethanol-diesel blend. Therefore generally the SOC of the both type biodiesel blends occurred earlier crank angle relative to E15 and DF at high load conditions.

In advanced common rail electronic fuel injection systems multiple injections are applied to decrease MPRR. It can be seen from the Fig.3 that MPRR result of the DF was calculated about 20.77-75.6 % higher than those of test blends at high engine load due to higher latent of heat vaporization of these blends compared with pure diesel. MPRR increased because of the increase in AB content in the E15 test blend at medium and high load conditions, while MPRR values of the VB blends increased with increasing biodiesel content only at high load condition. MPRR values of the E15 were obtained lower than those of E15AB20 and E15VB20 at high load condition.

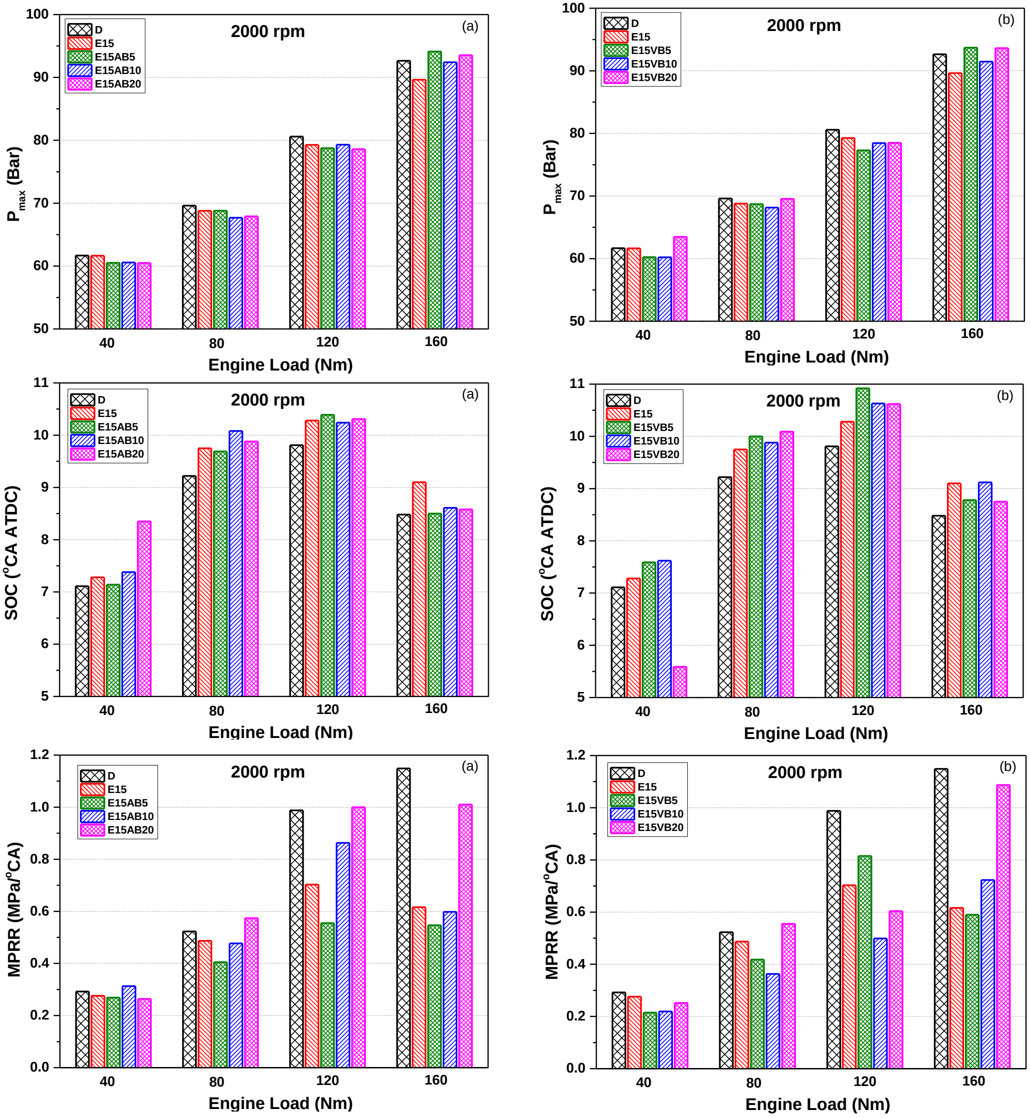

Fig. 3. Comparison of main combustion parameters results

Fig. 4 shows the BSFC results of the test fuels. As seen in the figure, the BSFC values decreased with increasing engine load for all test fuels expect for high engine load condition. The BSFC values of AB, VB blends and E15 were higher than those of DF for all test points. As the biodiesel added in the bioethanol-diesel blend, the BSFC values were obtained lower than that of E15 blend at high engine load condition. Alptekin et al. [19], Gürü et al. [22] and Yılmaz et al. [23] presented also higher BSFC values for biodiesels, biodiesel-DF or bioethanol blends with DF as compared to DF. The increase in BSFC was expected since the lower heating value of biodiesel fuels and bioethanol blends were lower than those of DF as given in Table 2. The lower heating values of AB, VB and bioethanol were about 13.07%, 12.63% and 37.03% lower than that of diesel fuel, respectively. This means that more amount of fuel is required for AB, VB and bioethanol blends than that of DF to obtain same engine power. Besides, two type biodiesels have higher density than E15 and DF which means more energy input per cycle for biodiesel-bioethanol-diesel blends. In this sense, the higher density of these blends can lead to increase in BSFC. One of the important results is BSFC values of the both type biodiesels are very close to each other for all test conditions although they have different fuel properties.

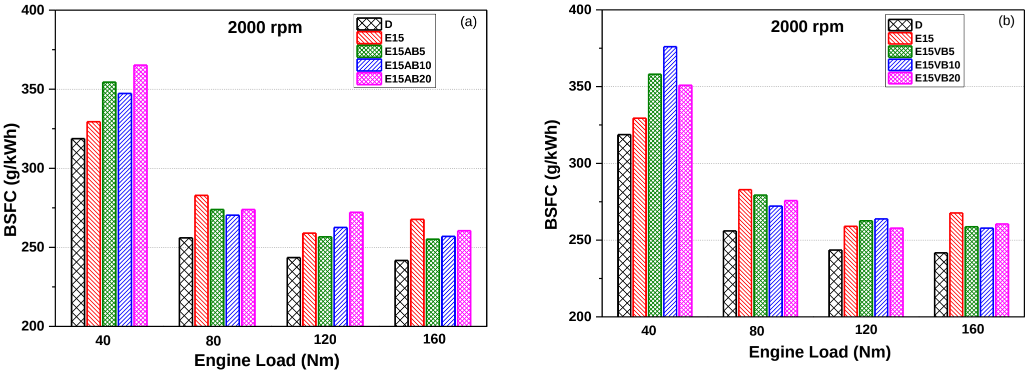

Fig. 4. Comparison of brake specific fuel consumption results

### 3.2. Emission characteristics

Fig. 5 shows the variations in NOx, smoke, THC and CO emissions for different operating conditions and for all test fuels at all test points. The emissions of NOx decreased with increasing engine load generally. It is known that biodiesel emitted higher NOx emissions due to higher oxygen content of the biodiesel when compared to diesel. The maximum NOx emission results were measured by using AB and VB blends for all test cases as seen in the Fig.5. The emissions of NOx depend on cylinder temperature, pressure, air-fuel ratio, combustion duration and oxygen content. For these reasons especially at high engine load $P_{max}$ values of the both types of biodiesel were measured higher than those of DF and E15 test fuels as given Fig.2, which leaded to increase in NOx emissions of the biodiesel blends. In addition, NOx emissions increased slightly with increase in biodiesel content in the blends at high engine load condition, while NOx emissions decreased by the addition of bioethanol to the neat diesel fuel due to higher heat of vaporization of the ethanol.

As shown in Fig. 5, smoke emissions were strongly affected by adding bioethanol and biodiesel to the diesel fuel. Smoke emissions showed contrary trends as compared to NOx emissions. Smoke emissions increased when engine load increased. At the same time, smoke emissions of AB, VB, E15 fuel blends were measured to be lower than those of DF for all engine loads due to increasing amount of oxygen content. It was found that the smoke emission decreased with the increase of AB and VB contents in the fuel blends at medium and high load conditions. As clearly seen in Fig.5, the smoke emissions decreased with increasing biodiesel content in the bioethanol-diesel blend for both types of biodiesel at high engine load conditions. Simultaneously, the smoke emissions decreased with the addition of bioethanol content for all test conditions.

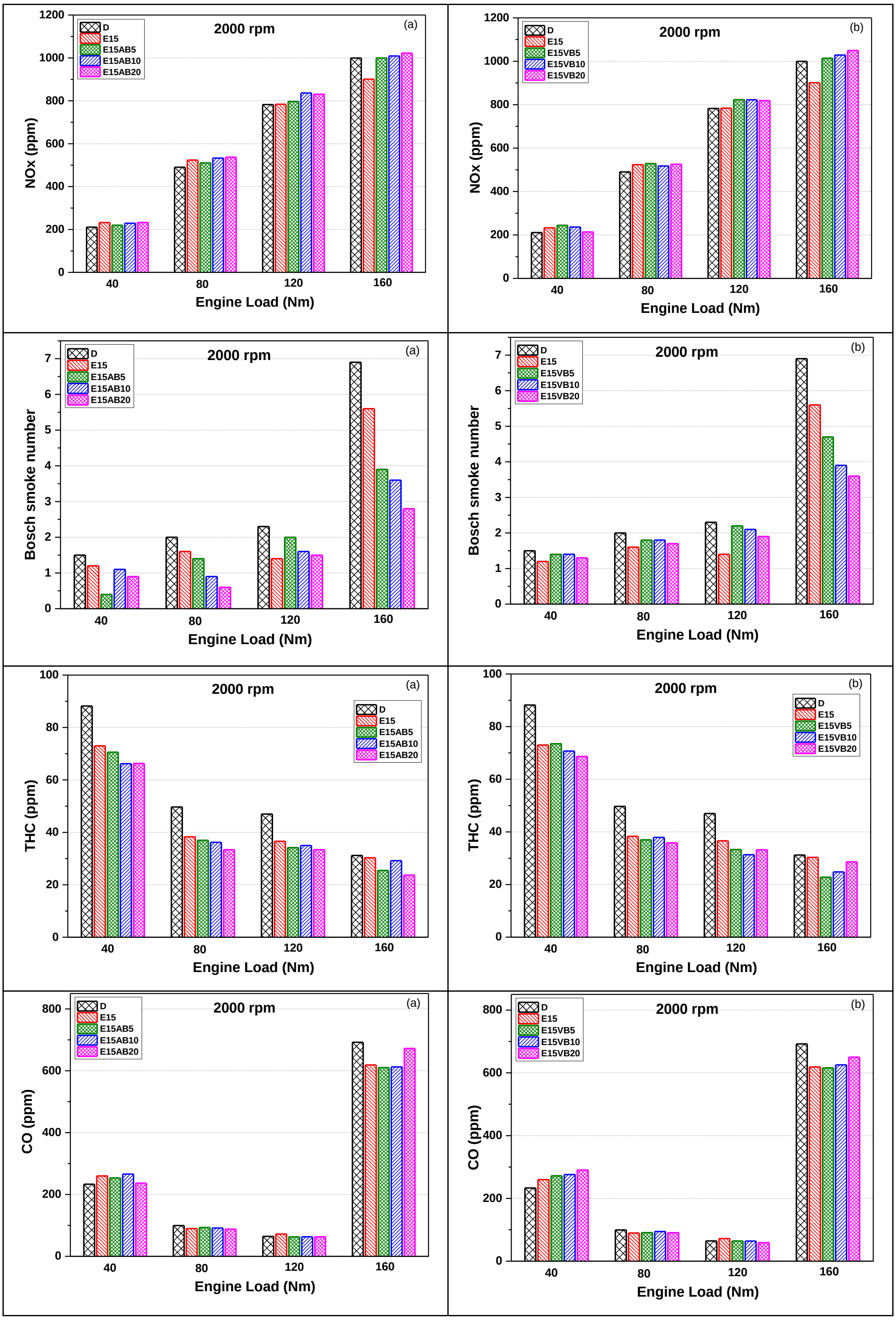

Fig. 5. Comparison of emission characteristics results

Fig. 5 shows the comparison of THC emissions of the test fuels. The results showed that THC emissions decreased with increasing engine load for all test fuels. This can be explained that decrease in engine load leads to decrease cylinder gas pressure and temperature. This result tends to slow vaporization and incomplete combustion and higher THC emissions [23].

The maximum THC emissions were measured with DF fuel, while the lower THC emissions were obtained by using AB and

VB blends as compared with E15 and DF for all test cases. It can be clearly explained that the higher oxygen content of biodiesel and bioethanol blends improve the combustion process. This leads to decrease in THC emissions, although bioethanol and biodiesel blends have higher latent of heat vaporization as compared to neat diesel fuel. The second reason why the THC emissions of the bioethanol-diesel-biodiesel blends were lower when compared to E15 can be related with shorter auto ignition time due to adding the biodiesel to the E15 increased to the cetane number of the AB and VB blends. In addition there is no any different trend that was observed on the THC emissions between two types of biodiesel.

It is obvious that CO emissions decreased with increasing the engine load from 40 Nm to 120 Nm, while the maximum CO emissions were measured at high load condition. Since more fuel is required for higher engine loads, CO emissions increased due to richer fuel-air mixture and reduce oxidation processes. In addition, there is corresponding decrease in CO emissions of the AB, VB and E15 test blends at high engine load which is due to higher oxygen and lower carbon amount in structure of bioethanol when compared to diesel. On the other side CO emissions produced by the combustion of blends were higher than that of DF at low load. This can be associated with richer fuel-air mixture and lower cylinder gas pressure of the test blends. As seen from the Fig. 5. AB and VB blends have same trends on the emissions characteristics as well.

## 4. Conclusion

In this paper, the effects of the different type biodiesels and content in the bioethanol-diesel blend were investigated on the combustion, performance and emissions characteristics of an electronic controlled common rail diesel engine by using double fuel injection under constant engine speed (2000 rpm) and four different engine loads (40 Nm, 80 Nm, 120 Nm and 160). In this sense, two different types of animal and vegetable biodiesels at different ratios varied at %5, %10 and %20 by mass in the bioethanol-diesel-biodiesel blends were used, while bioethanol-diesel concentration was maintained constant. At the end of the study, the following main conclusions were reached:

- ➢ Cylinder gas pressure patterns and heat release curves were observed very close to each other for AB and VB blends for all operating conditions.
- ➢ At high engine load condition, the maximum HRR values were obtained by using E15AB5 and E15AB20 for AB blends, E15VB5 and E15VB20 for VB blends as well. $P_{max}$ of the DF was observed about 2.42- 4.25% higher than those of test blends at low and medium loads.
- ➢ The SOC of the both types of biodiesel blends occurred earlier crank angle relative to E15 and DF at high load conditions.
- ➢ MPRR results of the DF were obtained higher than those of E15, VB and AB blends at high engine load. MPRR increased due to the increase in AB and VB content in the E15 test blend at high load condition.
- ➢ The BSFC values of AB, VB blends and E15 were higher than that of DF. BSFC values of the both types of biodiesel were very close to each other for all test points.
- ➢ The maximum NOx emissions results were measured by using biodiesel blends for all test cases. NOx emissions increased slightly with increase in biodiesel content, while NOx emissions decreased by the addition of bioethanol to the DF at high load condition.
- ➢ The smoke emissions of AB, VB, E15 fuel blends were measured to be lower than that of DF for all engine loads. The smoke emissions decreased with the increase in both types of biodiesel content at high engine load.
- ➢ The maximum THC emissions were measured with DF fuel, while the lower

THC emissions were obtained by using AB and VB blends.

There was corresponding decrease in CO emissions of the AB, VB and E15 test blends at high engine load when compared to DF.

## Acknowledgements

This study was supported by the grants from Scientific Research Foundation of Kocaeli University and Izmit Municipality (Project Nos. 2008/APP002 and 2011/37). The authors would like to thank to Istanbul Leather Organized Industrial Zone, DB Agricultural Energy (İzmir) and Pankobirlik Bioethanol Manufacturing Plant (Konya) managements for supplying the feedstocks and bioethanol.

## 5. References

1. Sayin C., Canakci M. 2009. “Effects of injection timing on the engine performance and exhaust emissions of a dual-fuel diesel engine.” Energ Convers Manage 50:203-213.
2. Ajav EA, Singh B. Bhattacharya TK. 1999. “Experimental study of some performance parameters of a constant speed stationary diesel engine using ethanol diesel blends as fuel.” Biomass Bioenerg 17:357–65.
3. Li D, Zhen H, Xingcai L, Wu-Gao Z, Jian-Guang Y. 2005. “Physicochemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines.” Renew Energ 30(6):967–76.
4. Rakopoulos CD, Antonopoulos KA, Rakopoulos DC. 2007. “Experimental heat release analysis and emissions of a HSDI diesel engine fueled with ethanol–diesel fuel blends.” Energy 32(10):1791–1808.
5. Rakopoulos, D.C., Rakopoulos C.D., Kakaras, E.C., Giakoumis E.G. 2008. “Effects of ethanol–diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine.” Energ Convers Manage 49:3155–62.
6. Gnanamoorthi V., Devaradjane G. 2015. “Effect of compression ratio on the performance, combustion and emission of DI diesel engine fueled with ethanol diesel blend.” J Energy Inst 88:19-26.
7. Sayin C. 2010. “Engine performance and exhaust gas emissions of methanol and ethanol–diesel blends.” Fuel 89:3410-15.
8. He B, Shuai S, Wang J, He H. 2003. “The effect of ethanol blended diesel fuels on emissions from a diesel engine.” Atmos Environ 37:4965–71.
9. Kumar S., Cho J.H., Park J., Moon I. 2013. “Advances in diesel–alcohol blends and their effects on the performance and emissions of diesel engines.” Renew Sust Energ Rev 22:46–72.
10. Ren Y, Huang ZH, Jiang DM, Li W, Liu B, Wang XB. 2008. “Effect of the addition of ethanol and cetane number improver on the combustion and emission characteristics of a compression ignition engine.” Proc Inst Mech Eng Part D –J Automob Eng 222:1077–87.
11. Armas, O., Martínez-Martínez, S., Mata, C. 2011. “Effect of an ethanol–biodiesel–diesel blend on a common rail injection system.” Fuel Process Technol 92:2145–53.
12. Guido, C., Beatrice, C., Napolitano, P. 2013. “Application of bioethanol/RME/diesel blend in a Euro5 automotive diesel engine: Potentiality of closed loop combustion control technology.” Appl Energ 102:13–23.
13. Yılmaz N., Vigil FM., Donaldson AB., Darabseh, T. 2014. “Investigation of CI engine emissions in biodiesel–ethanol–diesel blends as a function of ethanol concentration.” Fuel 115:790–793.
14. Yilmaz N. 2012. “Effects of intake air preheat and fuel blend ratio on a diesel engine operating on biodiesel–methanol blends.” Fuel 94:444–7.
15. Shahir S.A., Masjuki H.H., Kalam M.A., Imran A., Rizwanul Fattah I.M., Sanjid A. 2014. Feasibility of diesel–biodiesel–ethanol/bioethanol blend as existing CI engine fuel: An assessment of properties, material compatibility, safety and combustion.” Renew Sust Energ Rev 32:379-395.
16. Shahir S.A., Masjuki H.H., Kalam M.A., Imran A., Ashraful A.M. 2015. “Performance and emission assessment of diesel–biodiesel–ethanol/ bioethanol blend as a fuel in diesel engines: A review” Renew Sust Energ Rev 48:62-78.

17. Park S.H., Cha J., Lee C.S. 2012. “Impact of biodiesel in bioethanol blended diesel on the engine performance and emissions characteristics in compression ignition engine.” Appl Energ 99:334-343.
18. Beatrice, C., Napolitano, P., Guido, C. 2014. “Injection parameter optimization by DoE of a light-duty diesel engine fed by Bio-ethanol/RME/diesel blend.” Appl Energ 113:373–384.
19. Alptekin E., Canakci M., Ozsezen A.N., Turkcan A. Sanli H. 2015. “Using waste animal fat biodiesels- bioethanol-diesel fuel blends in a DI diesel engine.” Fuel 157:245-254.
20. Venu H., Madhavan V. 2017. “Influence of diethyl ether (DEE) addition in ethanol-biodiesel-diesel (EBD) and methanol-biodiesel-diesel (MBD) blends in a diesel engine” Fuel 189:377-90.
21. Parthasarathy M., Lalvani J.Isaac JoshuaRamesh., Dhinesh, B., Annamalai, K. 2016. “Effect of hydrogenonethanol–biodiesel blend on performance and emission characteristics of a direct injection diesel engine” Ecotoxicology and Environmental Safety 134:433-39.
22. Gürü M, Koca A, Can Ö, Çınar C, Şahin F. 2010. “Biodiesel production from waste chicken fat based sources and evaluation with Mg based additive in a diesel engine.” Renew Energ. 35:637-643.
23. Yilmaz N. 2012. “Comparative analysis of biodiesel-ethanol-diesel and biodiesel-methanol-diesel blends in a diesel engine.” Energy 40:210-3.