UNIVERSITY OF PITESTI
Faculty of Mechanics and Technology

SCIENTIFIC BULLETIN
AUTOMOTIVE series, year XXIV, no. 28

THE 11TH EDITION OF
The International Congress of Automotive and Transport Engineering
MOBILITY ENGINEERING AND ENVIRONMENT
November 8-10, 2017

# Emissions characteristic of diesel engine fueled by biodiesel at partial load

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**Article history**
Received 10.06.2017
Accepted 28.09.2017

**DOI** https://doi.org/10.26825/bup.ar.2018.011

**Abstract.** All This paper investigates the performance and emissions characteristics of a diesel engine fueled by biodiesel at partial load conditions. Experiments were conducted on a Renault K9K common-rail fuel injection diesel engine using mineral diesel and blends fuels of 6% and 10% with biodiesel obtained from corn oil and sunflower oil. The testes were made for 50%, 75% and 100% engine load. During experimental tests were measured the engine torque and the emissions of CO, CO2 and NOx. The engine torque for engine fueled with biodiesel blends is higher than for diesel fueled with mineral diesel in all tests. The CO and NOx, emissions decrease for all blends, and the CO2 increase. These are the results of better oxidation and of lower carbon content of biofuels.

## 1. Introduction

Generally, biofuels can provide an excellent opportunity to reduce some of the harmful emissions without costly engine changes. Because vegetable oils satisfy the main requirements of the diesel engine, in the latest years has been investigated their use as alternative fuels.

From all biofuel for diesel engines, biodiesel is a promising fuel, because it is a sulfur-free, non-toxic, oxygenated, renewable biofuel, and more than 90% can be biodegradable within 21 days [1].

Due to differences in chemical and thermal-physical properties (higher density, viscosity, cetane number, bulk modulus, and oxygen content) are differences in biodiesel’s performance, combustion and emissions characteristics [2]. Biodiesel has a shorter ignition delay than diesel due to a higher cetane number and a better combustion due to additional oxygen content. Because of lower heating

value of biodiesel the maximum power of the engine can be smaller. To compensate the loss of power a larger amount of biodiesel should be injected into the combustion chamber [3].
Diesel engines mostly operate under partial load conditions, especially for cars. Therefore, it would be more valuable and important to evaluate the performance of biodiesel during partial load conditions.
In this paper corn oil and sunflower oil biodiesel were tested at 50%, 75% and 100% engine load conditions.

## 2. Experimental setup

The experiments were made on a Renault K9K common rail fuel injection diesel engine. A schematic diagram of the engine test bed is shown in Figure 1. The engine specifications are presented in table 1. The engine test bed is equipped with an electric Dynas3 LI250 dynamometer, which is designed for operated within a range of 0-8000 rotations per minute. It can measure engine power up to 250 kW with an accuracy of ±2%. For the measurement of CO and NOx emissions was used the HGA 400 Pierburg chemiluminescence analyser. This analyzer can measure CO emission between 0 and 10% vol, with accuracy of 0.01%; for the NOx emission the range is between 0 and 5000 ppm, with an accuracy of 1 ppm.

**Table 1.** Engine properties.

| | |
|---|---|
| Engine type | Renault K9K four stroke |
| Number of cylinders | 4 |
| Bore (mm) | 76 |
| Stroke (mm) | 80.5 |
| Total displacement ($cm^3$) | 1451 |
| Compression ratio | 15.3 |
| Fueling | Common-rail direct injection |

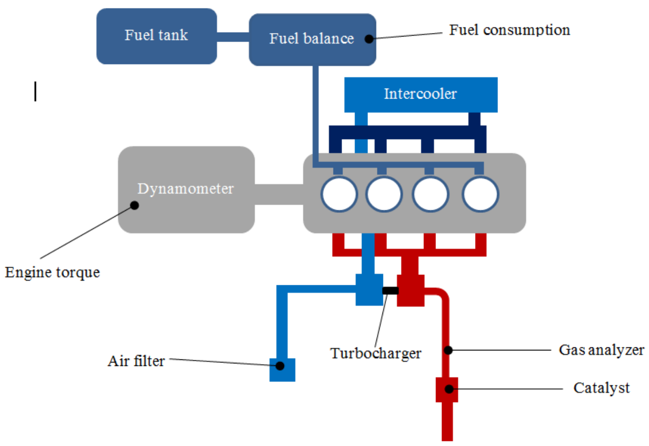


**Figure 1.** Schematic diagram of the engine test bed

In the present paper, biodiesel and its blends (Diesel, B6 and B10) were studied at different engine speed from 1200 rpm to 3700 rpm with an interval of 500 rpm and for three different engine loads 50%, 75% and 100 %.
The biodiesel was produced from corn oil and sunflower oil. The properties of fuels used in the tests are presented in table 2.

**Table 2.** Tested fuels properties.

| Fuel | D | B6C | B10C | B6SF | B10SF |
|---|---|---|---|---|---|
| Density at 20°C ($kg/m^3$) | 840.2 | 841.7 | 842.4 | 841.9 | 843.1 |
| Viscosity at 20°C ($mm^2/s$) | 5.34 | 5.04 | 4.99 | 5.27 | 5.10 |
| Cetane number | 51.1 | 57.6 | 62.1 | 54.5 | 57.6 |
| Flash point (°C) | 67 | 71.4 | 67.3 | 67.2 | 67.8 |

| | | | | | |
|---|---|---|---|---|---|
| Caloric value (MJ/kg) | 43.16 | 42.63 | 42.27 | 42.58 | 42.19 |

D – Diesel fuel, B6C – 6% biodiesel from corn oil, B10C – 10% biodiesel from corn oil B6SF – 6% biodiesel from sunflower oil, B10SF – 10% biodiesel from sunflower.

The engine was running at medium speed and load until the cooling water temperature stabilizes at 80$^{o}$C.

## 3. Results and discussions

*1.1. Impact of biodiesel blends on engine torque*

Figure 2 presents the variation of engine torque under full load for diesel and blends (6% and 10%) with biodiesel form corn oil and sunflower oil.

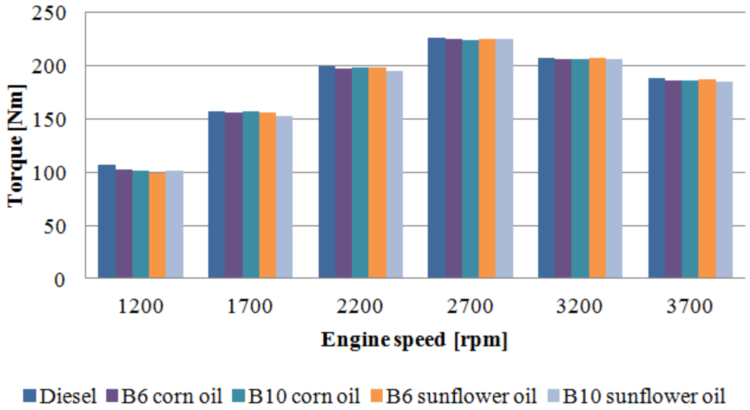


**Figure 2.** Variation of engine torque at full load.

The torque values for all tested fuels increase with the increase of engine speed until 2700 rpm, and then the torque decrease. For all blends tested was observed a small drop compared to diesel fuel. The maximum reduction is for B6 form sunflower oil at 1200 rpm (7.8%) and the smaller reduction is for B6 for sunflower oil at 2700 rpm (0.1%). These declines are due to the lower calorific value for the blends of biodiesel.

*3.2 Impact on carbon monoxide emissions.*

Figures 3, 4 and 5 present the CO emissions for 50%, 75% and 100% engine load. It is observed that the emissions of CO decreases with the increasing of the engine speed. The CO emissions for blends are bigger for the 6% blends versus 10% blends because the extra oxygen atoms contained into the biodiesel reduce the fuel-air ratio and provide a better fuel burning.

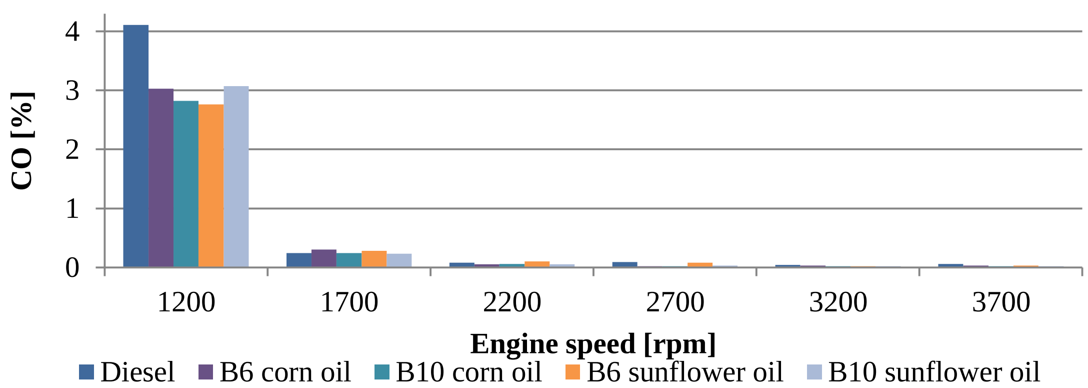


**Figure 3.** Carbon monoxide (CO) emission at 50% engine load.

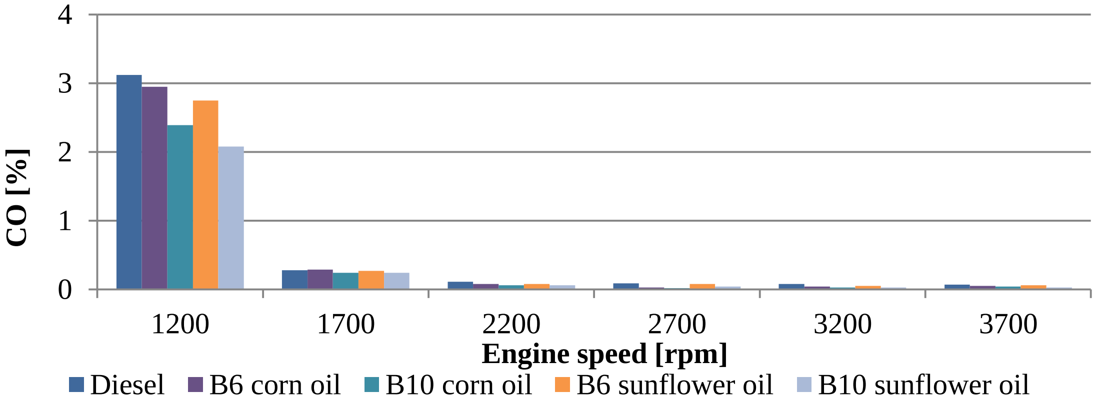


**Figure 4.** Carbon monoxide (CO) emission at 75% engine load.

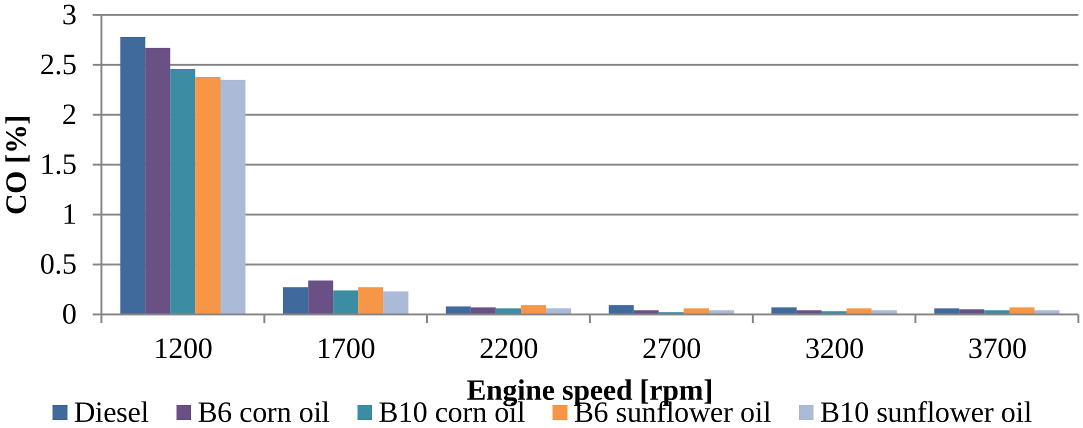


**Figure 5.** Carbon monoxide (CO) at 100% load.

Also the CO emission decreases with the increasing engine load. At lower load combustion conditions, the air fuel ration becomes too lean for a complete combustion, especially at lower engine speeds. The greater viscosity of the blends plays a role on combustion process during partial load conditions, increasing the tendency for an incomplete combustion.

With the increasing of engine load the CO emission decrease. This is because with the increase of engine loads, the fuel injection pressure increase and cancels the effect of higher viscosity of biofuels. Because of higher injection pressure the fuel spray is mixing better with the air from the cylinder and implicitly a more complete combustion. And the oxygenated nature of biodiesel becomes advantageous which tends to result in more complete combustions and reduces the CO emissions.

*3.3 Impact on carbon dioxide emissions.*

Figures 6, 7 and 8 present the $CO_2$ emissions for 50%, 75% and 100% engine load. For all partial load and full load the emission of carbon dioxide is greater when the engine is fueled with biodiesel blend. This increase of emission could be due to the higher density of biodiesel. The fuel injection is made volumetric. Due to higher density of biodiesel is injected a larger mass of fuel under complete injection. Another explanation is that the biodiesel give a more complete combustion, and the CO is transformed in $CO_2$.

For the biodiesel from corn oil the emissions of $CO_2$ is higher for 6% blends and for biodiesel from sunflower oil the emissions is higher for 10% blends. The flash point for 6% biodiesel form corn oil blend is higher than the flash point of 10% biodiesel form corn oil blend. Due of this the B6 from corn oil had a less complete combustion than B10 from corn oil.

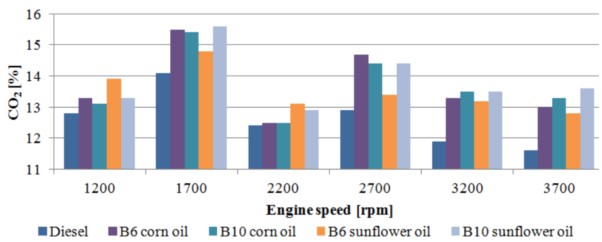


**Figure 6.** Carbon dioxide ($CO_2$) at 50% load.

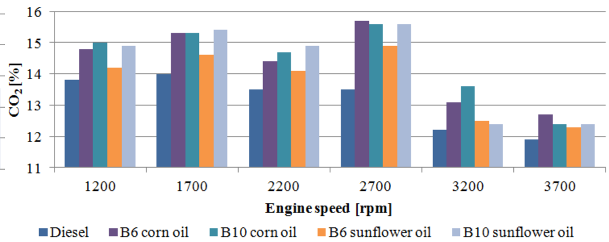


**Figure 7.** Carbon dioxide ($CO_2$) at 75% load.

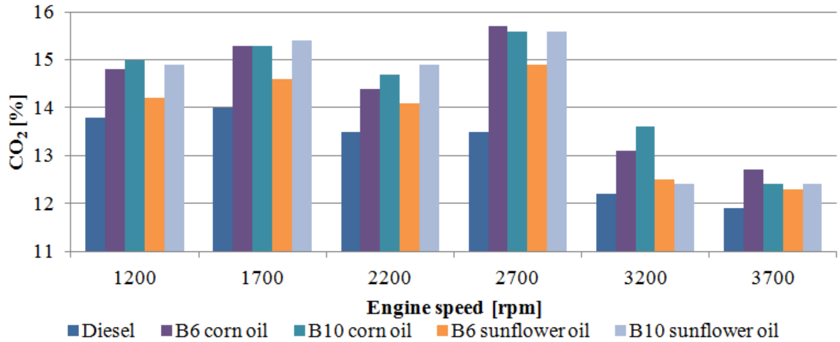


**Figure 8.** Carbon dioxide ($CO_2$) at 100% load.

Another reason for the higher value of $CO_2$ emissions of blends is the supplementary oxygen contents of biodiesel that transform the CO emissions in $CO_2$ emissions.
Compared with the CO emissions, the impact of partial loads on $CO_2$ emissions is less pronounced.

*3.4 Impact on nitrogen oxide emissions.*

Figures 9, 10 and 11 present the $NO_x$ emissions for 50%, 75% and 100% engine load. For all tested fuels the $NO_x$ emissions increase with the increases of engine speed and decreases with the increases of the engine load.

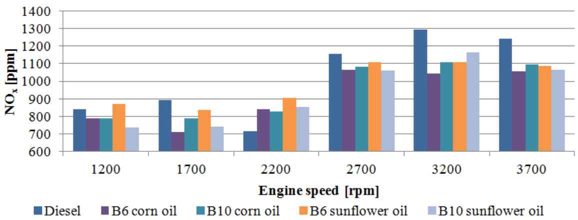


***Figure 9.*** *Nitrogen oxide ($NO_x$) at 50% load.*

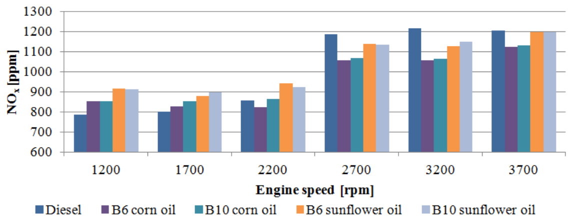


***Figure 10.*** *Nitrogen oxide ($NO_x$) at 75% load.*

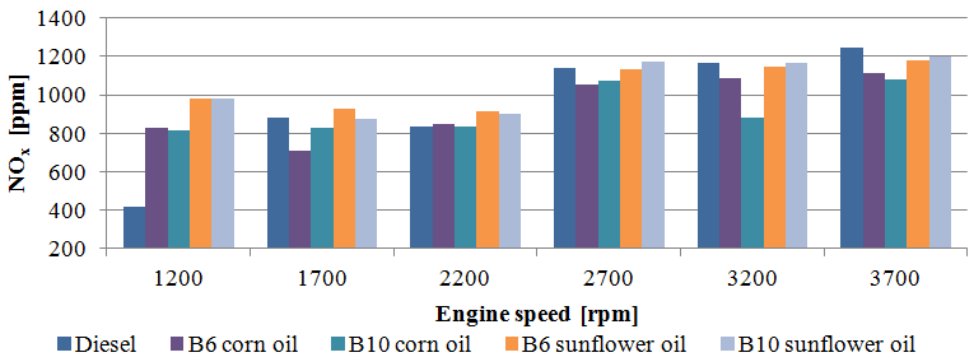


**Figure 11.** Nitrogen oxide ($NO_x$) at 100% load.

The $NO_x$ emission is sensitive to the combustion temperature. It is agreed that a higher temperature in the cylinder generate a higher $NO_x$ emission. Because the cylinder temperature can not be measured, the exhaust temperature has been used as a comparison factor. The exhaust temperature was smaller when the engine was fueled with biodiesel blends. The exhaust temperature increases with the increasing of load and speed. Generally the $NO_x$ emission was smaller when the engine was fueled with biodiesel blends.

For all partial and full loads, at small and medium engine speed (1200 rpm – 2200 rpm) the $NO_x$ emission was greater for biodiesel blends. At higher engine speed (2700 rpm – 3700 rpm) the $NO_x$ emission was greater for diesel fuel.

## 4. Conclusions

In this study, the experiments were made using mineral diesel fuel and four blends (6% and 10%) with biodiesel obtained from corn oil and sunflower oil to investigate the impact of biodiesel on performance and emission characteristics of diesel engine at partial and full load.

Due to the lower calorific value of biodiesel blends, the engine torque was smaller for all biodiesel blends.

The CO emission decreases with the increasing of the engine speed and decreases with the biodiesel blend ratio. The CO emission decreases with the increasing of the engine loads because the fuel spray is mixing better due to the increases of the fuel pressure injection. The supplemental oxygen helps to a better combustion and reduces the CO emission.

The $CO_2$ emission is higher for all biodiesel blends. One of the reasons is the greater density of the biodiesel blends. The injection of fuel is made volumetric, so the mass of fuel injected is greater for biodiesel blends. Another reason is the supplemental oxygen that helps to transform the CO in $CO_2$ emission. For $NO_x$ the variation is random.

## 5. References


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