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Performance analysis of a common-rail Diesel engine fuelled with different blends of waste cooking oil and gasoil

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Abstract

An experimental campaign was performed to study the behavior of a common-rail Diesel engine in automotive configuration when it is fuelled with blends of Diesel fuel (DF) and waste cooking oil (WCO). In particular the tested fuels are: B20 blend, composed of 20% WCO and 80% DF; B50, composed of 50% WCO and 50% DF; WCO 100% and 100% DF.

In order to fuel the engine with fuel having a similar viscosity, this quantity, together with density, has been measured at temperature ranging from rom to about 80 °C. According to these measurements, before fuelling the engine B20 was heated up to 35 °C and B50 to 75 °C.

An in-house software was developed to acquire the data elaborated by the electronic control unit.

Results show the trend in torque and global efficiency at different gas pedal position (gpp) and different engine speed. The experiments show that larger discrepancies are measured at smaller gpp values, while at larger ones differences become smaller. A similar trend is noticed for engine global efficiency.

Keywords: biofuels; waste cooking oil; gasoil blends; common-rail engine; performance analysis.

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1. Introduction

In 2013, EU emitted more than 4600 million tonnes of CO_2 equivalents [1], around 22% of which are due to transport [2], making it the second biggest greenhouse gas (GHG) emitting sector in EU after energy. Road transport represents about 72% of the total greenhouse gas emissions in transport, and about one-fifth of the EU's total. While emissions from other sectors are generally decreasing, those from transport have continued to increase from 1990 until 2008; in 2008 the enhanced efficiency of passenger cars and slower growth in mobility due to the economic crisis, induced a decrease in GHG emissions also from transport [3]. However, the EU motor vehicle market is increasing and in it the Diesel engines share is about 56% [4].

The EU adopted some measures to reduce emissions from different modes of transport, the most important of which is probably comprised within the Directive 2009/28/EC [5]. This Directive fixes some important goals to be achieved by 2020, and among others there is one goal specific for transport: by 2020 at least 10% of the fuels used in this sector must be renewable. This implies that a big effort is needed to develop a new generation of fuels and to enhance the use of those already available.

For Diesel engines the most suitable renewable fuel available nowadays is bio-diesel (BD), which is a bio-fuel mostly derived from vegetable oils. Its properties are similar to those of Diesel fuel (DF) and it can be used both in blends with DF or alone ([6]-[10]). Unfortunately, the spread of the use of BD is limited by the high investment needed to produce it [11]-[13]. Therefore, to be economically attractive the BD production requires large volumes of oils, and this in turn limits the development of such production plants. A possible way to bypass this problem was suggested by Rudolf Diesel in 1912 [14]:*"It has been proved that Diesel engines can be worked on earth-nut oil without any difficulty [...]. This oil is almost as effective as the natural mineral oils [...]. The fact that fat oils from vegetable source can be used may seem insignificant today, but such oils may perhaps become in course of time of the same importance as some natural mineral oils and the tar products are now. [...] In any case, they make it certain that motor power can still be produced from the heat of the sun , which is always available for agricultural purpose, even when all our natural stores of solid and liquid fuels are exhausted."*. The use of pure vegetable oils as fuel results in even smaller GHG emissions when comparing with those of biodiesel, since no emissions come from the biodiesel production process. However, in EU the amount of land that could be devoted to oilseed crops is limited, thus pure vegetable oils cannot be seen nowadays as a global alternative to DF. The situation may change with the use of oil from algae, which are very promising because of their large productivity [15]-[17]. In the meanwhile, we can still use vegetable oils in some niche applications, i.e., public transport, hybrid and marine propulsion, electricity generation units, etc.

In this framework, another way to widen the available alternative biofuels for Diesel engines is using waste cooking oil (WCO). This oil has to be disposed as it is pollutant (one liter of WCO is sufficient to make not drinkable about one million liters of water [18]), thus its use as fuel would be twice beneficial. However, since WCO properties are very different from those of DF, its use in Diesel engine might results in possible problems. Some years ago we started an experimental campaign to study the effect of the use of pure vegetable oils and WCO as fuels in engine performance and pollutant emissions [19]-[21]. In the present work, we study the mechanical performance of a common-rail Diesel engine in automotive configuration using blends of WCO and DF.

2. Materials and methods

2.1. Experimental setup

The engine used for tests is a four strokes, common-rail, turbocharged Diesel engine with a JTD injection system. The main characteristics of the engine are reported in Table 1. This engine was taken from a road vehicle and was installed on the bench test in the engine room of the Department of Mechanical and Aerospace Engineering of the Sapienza Università di Roma, Italy. Gear box and flywheel were removed to install the engine to the test bench. Drive shaft was connected to the hydraulic brake through a cardan joint; the engine air intake is at constant temperature (about 25 °C). An electric centrifugal fan was placed in front of the radiator in order to cool it. The original fuel tank was replaced with a bi-fuel system designed on purpose. It is composed of two tanks (one for DF and one for the biofuel), each of which connected to the fuel pump through a switching system, which allows to fuel the engine with one of the two fuels. The biofuel tank is equipped with a temperature control system in order to pre-heat the fuel. A part from these modifications, the engine is equipped with the original auxiliary and injection systems and electronic control unit (ECU). That is, the engine can be considered in automotive configuration. Further details on the the experimental setup can be found in [19]-[21].

Table 1. Characteristics of the engine used for tests

Engine	1.9 JTD
Cycle	Diesel, 4 strokes
Cylinder capacity	1910 cm^3
Number of cylinder	4
Torque max.	205 Nm @ 1500 rpm
Power max.	77 kW @ 4000 rpm
Injection type	Common-rail, Bosch Unijet

A specific software was developed for data acquisition using the engine original equipment (i.e., sensors and CAN-Bus). The most relevant engine parameters were acquired by connecting a PC to the OBD; torque and power were measured through the bench test.

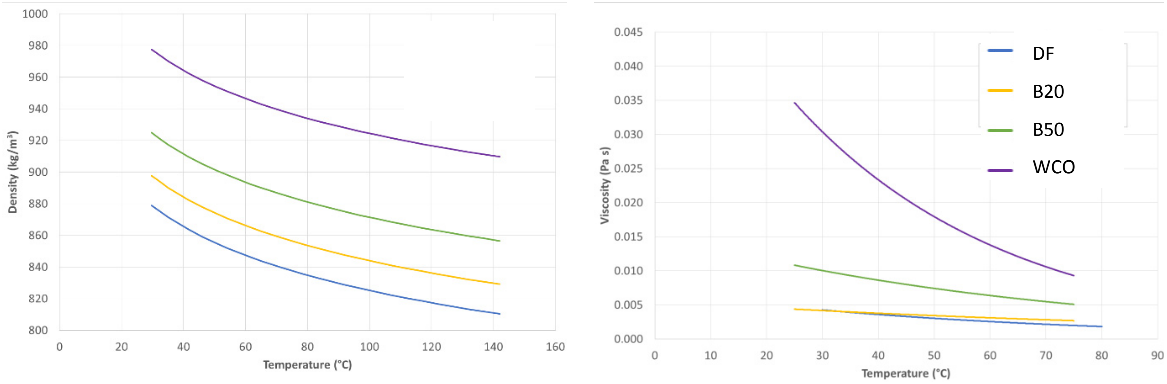

Figure 1. Density (left) and viscosity (right) of the tested fuels.

2.2. Fuels properties.

Tests were conducted by using Diesel and WCO blends as summarized below:

- 20% WCO, 80% Diesel (B20);
- 50% WCO, 50% Diesel (B50);
- 100% WCO (WCO).
- 100% DF (DF)

WCO was only filtered in order to remove solid particles. To avoid problems to the pumping and injection systems, fuel viscosity and density were measured at different temperatures, and the results are showed in Figure 1. According to these measurements, in order to have a fuel viscosity similar to that of DF at room temperature, the two blends have been heated to 35 °C (B20) and 75 °C (B50), and the WCO (WCO) to 120 °C [21]. Main fuel properties at the thank temperature are summarized in Table 2.

2.3. Tests performed

For each of the tested fuels we varied the gas pedal position (gpp) at 20%, 40%, 60%, 80% and 100% of the full throttle position; for each gpp the engine speed was varied at 1300, 1600, 1900, 2200, 2500, 2700, 3100, 3400, 3700, and 4000 rpm. Three tests were performed for each fuel, and the results averaged.

Table 2. Main properties of the fuels tested

Fuel	**PCI [Mj/kg]**	**Density @ 25 °C [kg/m^3]**	**Dynamic viscosity [Pa*s]**	**Pre-heating temperature [°C]**
D100	44	888	0,004	-
B20	42,7	897	0,0045	35
B50	40,8	924	0,01	75
WCO	37,9	980	0,04	120

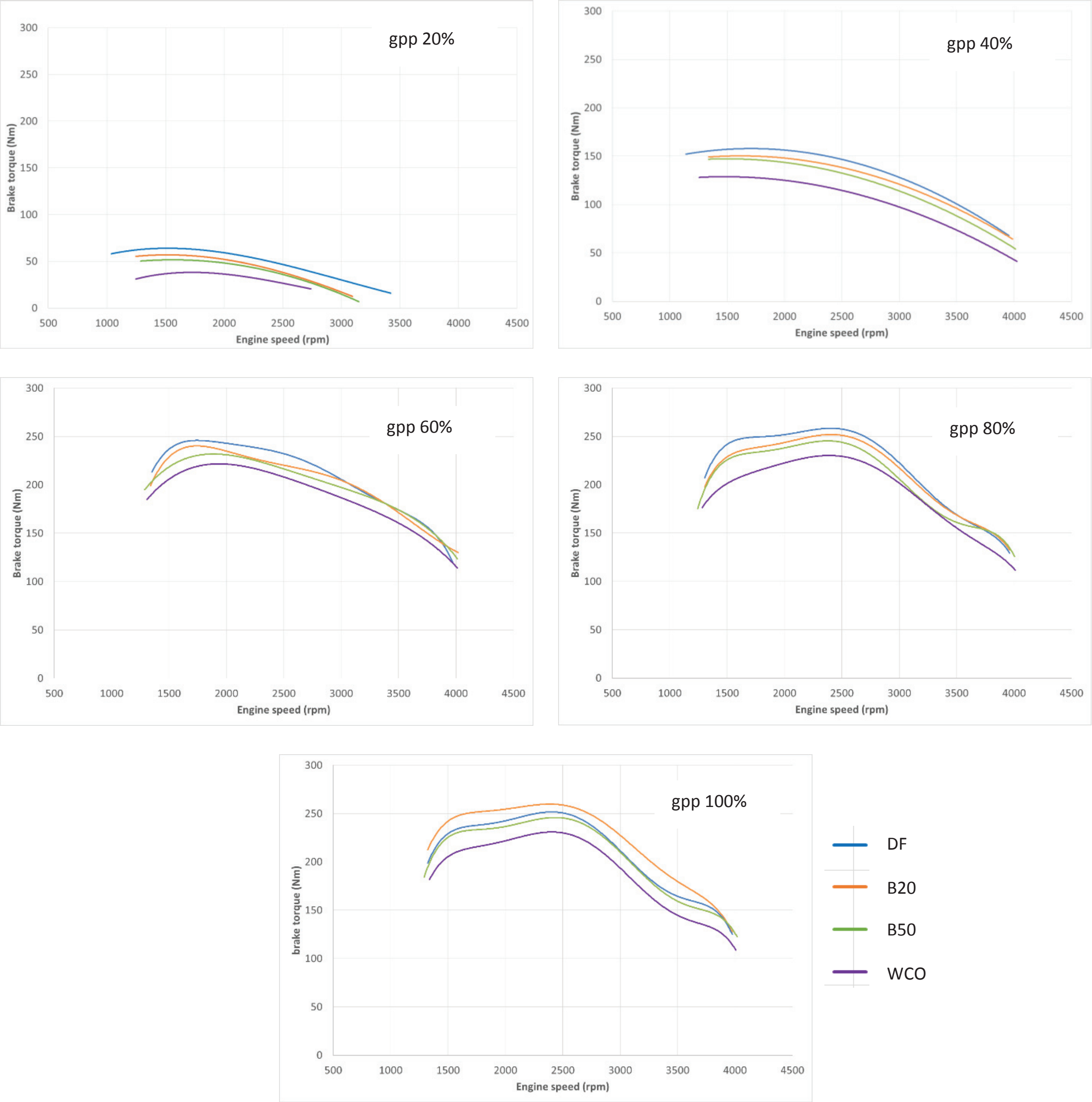

Figure 2. Brake torque as a function of engine speed at 20% gpp (top left), 40% gpp (top right), 60% gpp (middle left), 80% gpp (middle right), 100% gpp (bottom).

Table 3. Maximum brake power and torque and the respective engine speeds, for different gpp.

gpp	measured quantities	DF	B20	B50	WCO
20%	max *Brake power* [kW]	13.9	11	10.3	7.4
	rpm at max *brake power*	2200	2200	2200	2200
	max *Brake torque* [Nm]	63	56.7	50	37.2
	rpm at max *brake torque*	1600	1600	1600	1900
60%	max *Brake power* [kW]	65.3	66	64.8	60.5
	rpm at max *brake power*	3100	3100	3100	3100
	max *Brake torque* [Nm]	246	239	233	224
	rpm at max *brake torque*	1900	1900	1900	1900
100%	max *Brake power* [kW]	72	67.8	68.6	64
	rpm at max *brake power*	2700	2700	2700	2700
	max *Brake torque* [Nm]	260	250	245	228
	rpm at max *brake torque*	2500	2500	2500	2500

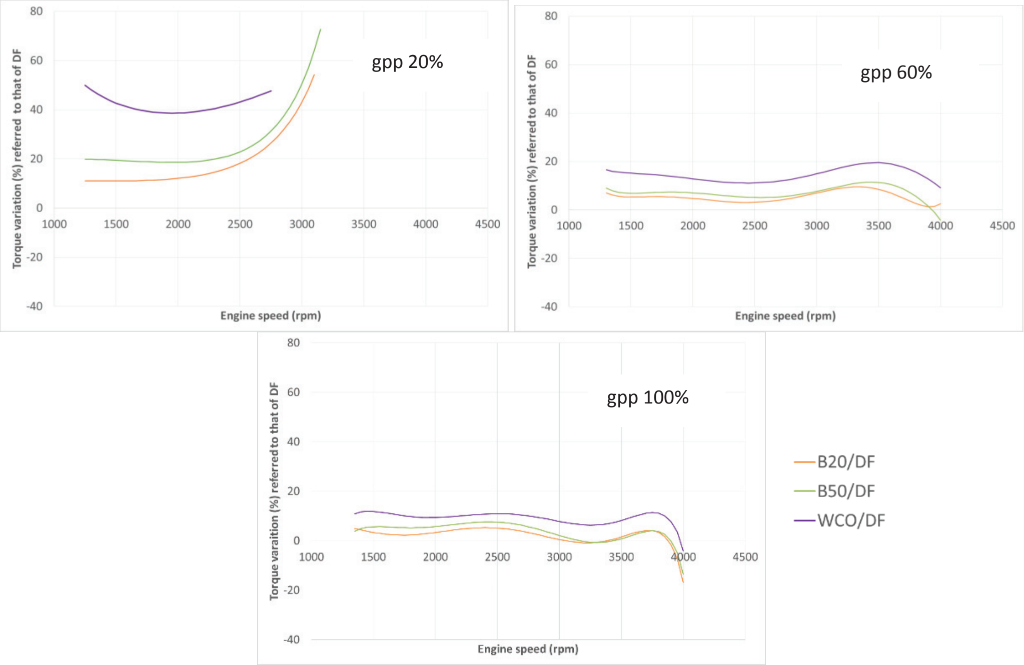

Figure 3. Brake torque deviation referred to that of DF, at 20% gpp (left), 60% gpp (middle), and 100% gpp (right).

3. Results and discussion

3.1. Brake torque

Brake torque for the four tested fuels and at the five different gas pedal position are shown in Figure 2.

Tests performed at 20% gpp with DF allows a maximum engine speed equal to 3400 rpm and not 4000 rpm as in the other tests. This is because the injected fuel quantity did not allow to reach larger torque (and power). This limit becomes even smaller when fuelling the engine with the two blends (about 3100 rpm) and with WCO (about 2700 rpm). As the gpp increases the maximum brake torque moves from about 1500 rpm (20% gpp) to about 2500 rpm

(100% gpp). Table 3 summarizes the maximum brake power and torque and the respective engine velocities at different gpp. Analyzing the torque curves (Figure 2) it comes out that the engine behaves almost in the same way when fueled with B20 and B50 at all the gpp values. The toque curves tend to become closer and closer to those of DF at high rpm (larger than 3500 rpm), while for smaller rpm they stay separate. This could be due to the high engine temperature measured in some tests. In particular, during some of the tests with DF, the engine temperature became larger than 105 °C, value at which the ECU cut the total fuel quantity injected within each cylinder. This can be also seen analyzing the torque deviation.

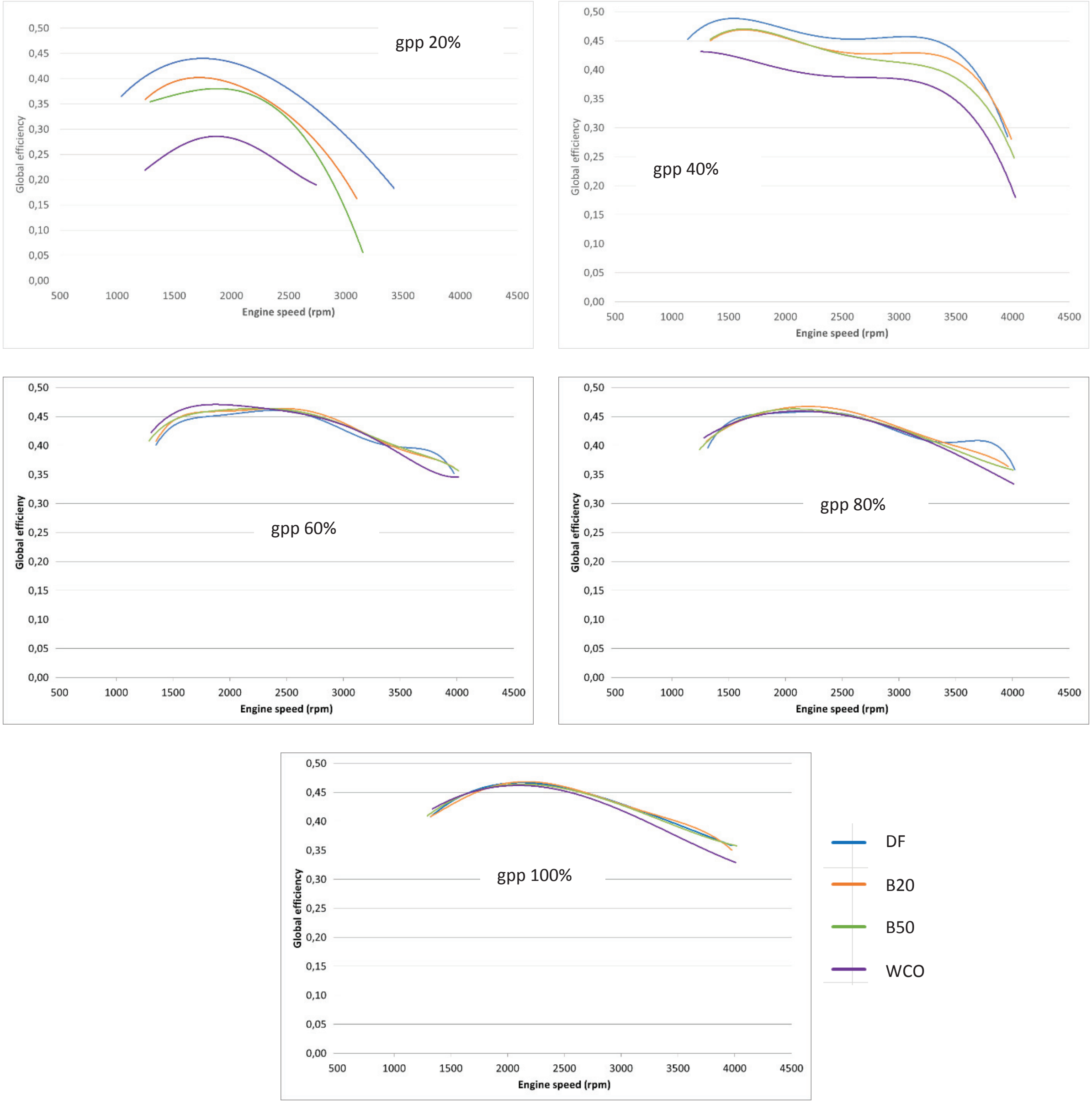

Figure 4. Global efficiency as a function of engine speed at 20% gpp (top left), 40% gpp (top right), 60% gpp (middle left), 80% gpp (middle right), 100% gpp (bottom).

Figure 3 shows the brake torque deviation (%) at 20%-60%-100% gpp for B20, B50 and WCO referred to that of DF. WCO shows the larger variations at all the gpp: at 20% gpp it equals about 40-50%, however the maximum variation is measured using B20 and B20 and is about 70%. This is only due to the fact the with WCO at 20% gpp the engine did not reach speeds larger than about 2750 rpm, while using B20 and B50 the speed measured were about 3150 rpm. As the gpp increases, the difference between the torques produced using different fuels reduces to about 10-20% at 60% gpp, and about 0-10% at 100% gpp.

3.2. Global efficiency

The engine global efficiency at different gpp is reported in Figure 4. At 20% gpp the differences in best global efficiency achieved with the tested fuels are the largest, ranging from about 0.29 with WCO at 1850 rpm, and 0.44 with DF at about the same engine speed. The maximum global efficiency using B20 is 0.4 at about 1800 rpm; for B50 we computed an efficiency of 0.38 at about 1900 rpm. The differences are quite big in this case (Figure 5). As the gpp increases, the global efficiencies tend to be closer each other, and the deviation from that of DF keep less then 5-6%. The only exception to this is the global efficiency with WCO at high engine speed: even at larger gpp it shows the largest deviation reaching values about 10% at 4000 rpm and 100% gpp.

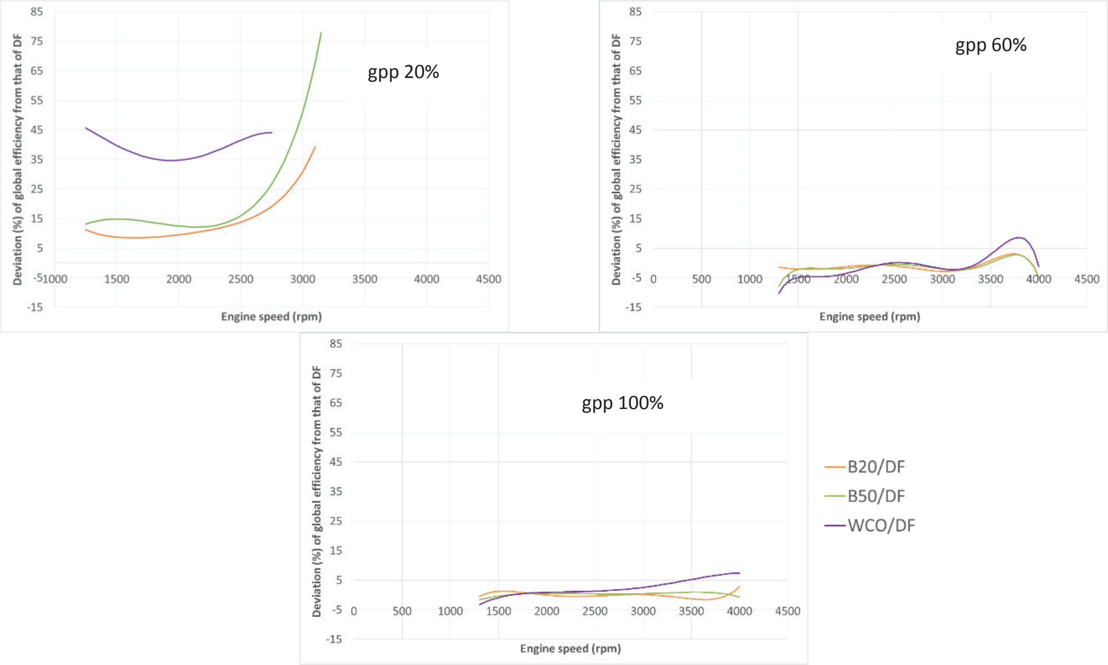

Figure 5. Global efficiency deviation referred to that of DF, at 20% gpp (left), 60% gpp (middle), and 100% gpp (right).

4. Conclusions

In the present work we tested the effect of using two different blends of WCO and DF in engine behaviour. The results were compared to those obtained using pure DF and WCO. In order to do this, we developed a in-house software able to read all the quantities red by the engine ECU.

The main issues related to the use of the two tested blends (B20 and B50) have been noticed at smaller gpp. Torque and global efficiency are the worst and the differences between the blends-WCO and DF are the largest. This is due to the several aspects: first, the difference in heating value of the fuels that reduces the torque and power provided by the engine. Second, the effect of auxiliary devices power consumption, that is larger (in percentage terms) at smaller regimes that at larger, and of course has a different weight for the different fuels tested. Moreover, also the combustion process and the injection time play a role in the engine behaviour.

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