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Impact of alternative fuels on performance and pollutant emissions of a light duty engine tested under the new European driving cycle

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HIGHLIGHTS

- ▶ Effect of animal fat biodiesel and GTL fuels on pollutant emissions under controlled NEDC has been studied.
- ▶ Regulated gaseous emissions were determined to evaluate the effect of alternative fuels along urban and extraurban cycles.
- ▶ The potential of fuels was also quantified through the measurements of smoke opacity and particle concentration.
- ▶ Reduction in particulate matter has been observed with the use of GTL and biodiesel fuels.

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ABSTRACT

Two alternative fuels, a gas to liquid (GTL) fuel from a low temperature Fischer–Tropsch process and a biodiesel produced from animal fats, have been tested using a light duty diesel engine with road load simulation (RLS) under the New European Driving Cycle (NEDC). The engine used has a variable geometry turbocharger (VGT), exhaust gas recirculation with cooling (EGR), common rail with split fuel injection and diesel oxidation catalyst (DOC). Regulated emissions have been evaluated and noticeable reductions in THC and CO were observed with both alternative fuels whereas only slight decrease was obtained in NOx emissions with biodiesel. With respect to results on particle matter, important reductions in both particle number and particle mass were obtained with both alternative fuels.

1. Introduction

The interest on alternative fuels for diesel engines has increased as a means to reduce the dependency on oil and to fulfill the increasingly stringent environmental legislation. In fact, to promote the use of “cleaner” fuels, the European Directive 2009/28/EC establishes the replacement of up to 10% the diesel consumption with renewable sources. Two types of “alternative” fuels could be distinguished.

On one hand, oxygenated fuels are known to decrease particle emissions derived from diesel combustion. Many oxygenated fuels have a renewable origin which favors the reduction of greenhouse gas emissions. Biodiesel, which is produced from vegetable oils or animal fats, is the oxygenated biofuel most widely used in diesel engines. Many works have been carried out with biodiesel in steady conditions and most of them report benefits in THC and CO emissions. These benefits are usually justified by the presence of oxygen in the fuel which favors a more complete combustion [1,2] although in low load conditions (relatively low temperatures) the low volatility of biodiesel could hinder the evaporation of fuel and reverse these trends. The notable reduction in PM emissions with biodiesel with respect to diesel fuel is mainly justified by, besides the presence of oxygen [3,4], the absence of aromatics [5]. Regarding NOx emissions, no unanimous tendency is reported in the literature. NOx emissions from biodiesel are usually higher than those observed with diesel fuel in steady conditions, although biodiesel made from saturated esters (as in the case of animal fats) usually present lower NOx values than unsaturated biodiesel [6–8].

On the other hand, synthetic fuels as those derived from Fischer–Tropsch processes show also many benefits for their use as alternative fuels. Depending on the raw material, fuels obtained from this process can be classified in gas to liquid (GTL), biomass to liquid (BTL) or coal to liquid (CTL), obtained from natural gas, biomass and coal, respectively, the first one being the most widely used. Usually, this conversion process is classified depending on the temperature level of the process and denoted as: Fischer

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Tropsch at low (LTFT) and at high temperature (HTFT). Fuels obtained from LTFT are usually used for diesel engines because they are mainly composed of paraffins (lack of aromatic compounds) which imply high cetane number, an important parameter for diesel fuels. Some works have been carried out comparing both types of Fischer–Tropsch fuels, obtaining lower particle mass emissions with both synthetic fuels with respect to diesel [9], the lowest values being obtained with LTFT.

Different studies have been carried out using GTL in steady conditions. In the most of them, reductions in CO and THC emissions were observed [10–12] with respect to diesel fuel, whereas no clear tendency is found on the effect of GTL on NOx emissions [13]. With respect to smoke opacity and PM emissions, notable reductions in smoke opacity and PM have been reported in many works [14–17], usually justified by the lack of poly-aromatics in its composition [18]. However, the higher cetane number of this synthetic fuel shortens the premixed combustion phase (longer diffusion phase) [19] which could offset the benefits in soot emissions with respect to those expected from the GTL composition. The impact of both alternative fuels (biodiesel and GTL) on the performance and emissions of light duty diesel engines has been widely studied but mainly under stationary operating conditions (as previously mentioned). On the contrary, due to the complexity of the testing facilities, this impact has been less studied in transient conditions [20–23], particularly in the case of GTL fuel [11,12,20].

In real driving conditions, engines mainly work at transient conditions where different parameters of the engine control management (turbo-lag, EGR valve response, injection timing, etc.) may change the trends obtained in steady state operation. This work deals with the study of the potential of these alternative fuels during transient conditions where lack of local oxygen in the combustion chamber, due to the operation turbochargers, significantly affects the formation of pollutant emissions [23].

Additionally, this work also addresses the evaluation of the potential of the mentioned alternative fuels on the reduction of the number of particles emitted per kilometer, a parameter which has been limited from September 2009 in the current Euro 5 legislation [24].

2. Experimental work

2.1. Engine and equipment

The experimental work was carried out in a 4 cylinder, 4-stroke, turbocharged, intercooled, 2.0 L NISSAN diesel engine with common-rail injection system (model M1D). The engine was equipped with cooled exhaust gas recirculation (EGR), oxidation catalyst (DOC) and regenerative wall-flow type diesel particle filter (DPF). The engine was linked to an asynchronous electric brake Schenck Dynas III LI 250 with a Road Load Simulation (RLS) tool. This tool has the capability for reproducing or simulating the load of a particular vehicle, in an engine test bed. In this work, a NISSAN Qashqai 2.0 dci was simulated during the tests. The main characteristics of both the vehicle and the engine are shown in Table 1. Besides, RLS allows simulation of different driver behavior. In this case, a calmed (neither hard nor soft) driver has been selected.

The INCA PC software and the ETAS ES 591.1 hardware were used for the communication and management of the electronic control unit (ECU). Fuel injection strategy was not externally controlled during the tests.

Downstream of the DOC, the exhaust pipe was modified with a by-pass (one line with DPF and the other one without DPF as shown in Fig. 1), in order to measure pollutant concentrations with and without the effect of diesel particle filter (DPF). To study the effect of fuel composition on emissions, in this work the exhaust gas always flowed through the line without DPF. A general scheme of the experimental installation is presented in Fig. 1.

Table 1
Main vehicle and engine characteristics.

Vehicle	
$C_d * A$ (m^2)	0.83
Weight (kg)	1608
Engine	
Cylinders	4
Displacement (cm^3)	1994
Bore (mm)	84
Stroke (mm)	90
Power max. (kW)	110 at 4000 min^{-1}
Torque max. (Nm)	323 at 2000 min^{-1}
Transmission	
Type	Manual 6 gears
1st Gear ratio	3.727
2nd Gear ratio	2.043
3rd Gear ratio	1.322
4th Gear ratio	0.947
5th Gear ratio	0.723
6th Gear ratio	0.596
Differential ratio	4.266
Tyres	
Code	215/65R16

CO and NOx gaseous emissions were measured with a heated non-dispersive infrared analyzer, and with a zirconia sensor, respectively, both with Horiba OBS-1300 System. For calculating relative air-fuel ratio and specific emissions, the inlet air mass flow rate was measured by means of the hot wire flow meter of the engine. Fuel mass flow rate was determined by the electronic control unit (ECU) previously calibrated with an AVL 733s fuel gravimetric system, following the method presented by Broatch et al. [25]. Both signals were registered by means of the INCA PC software. THC methane equivalent emissions were measured with a flame ionization detector AMLUK FID 2010 μP. All gaseous emissions were always measured downstream of the DOC.

An AVL 439 opacity meter was used to measure the smoke opacity and particle concentrations were determined by an Engine Exhaust Particle Sizer™ Spectrometer (EEPS), both with a sampling frequency of 10 Hz. The latter was coupled to a rotating disk diluter (RD) model MD19-2E, as primary dilutor, and an air supply thermal conditioner (TC) model ASET15-1 with an evaporating tube, as secondary dilutor. The rotating disk temperature was fixed at 150 °C and the thermal conditioner temperature was fixed at 300 °C. Temperatures at the dilution devices were selected in order to prevent gas sample cooling. Dilution factors and thermophoretic and diffusion losses were calculated using the calibration certificates provided by Matter Engineering AG. Primary dilution factor at RD was 180.2 and secondary dilution factor at the thermal conditioner was 6.45. Total dilution factor of the experimental configuration used was 1165:1, above 1000:1 as recommended by Kittelson et al. [26]. The particle size distributions per second presented in this work, correspond to mean results from 10 measured distributions. Table 2 shows the accuracy and the total response time of each gaseous analyzer.

2.2. Test conditions

The day before each test, a preconditioning procedure, described in [23], was carried out. Then, the tests for reproducing NEDC were conducted following the procedure described in Table 3. Tests with each fuel were repeated three times. The results shown correspond to the mean values.