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New European Driving Cycle assessment by means of particle size distributions in a light-duty diesel engine fuelled with different fuel formulations

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HIGHLIGHTS

- NEDC assessment by means of particle emission with six different fuels.
- Increase in the particle-energy ratio for biofuels and FT fuel.
- Particle concentration reduction during EUDC for biofuels and FT fuel.
- Decrease in PSD-mode for all fuel used compared to reference diesel fuel.

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ABSTRACT

In this study, an experimental investigation of particle size distribution emission over performance of transient conditions in a high speed diesel engine fuelled with diesel, biodiesel and Fischer Tropsch fuels have been assessed. Six fuels with different properties have been tested in a 4-cylinder light-duty diesel engine typically used for European passenger cars. The cycle used in this study was the New European Driving Cycle (NEDC) and each test was carried out after a stabilization warming period in order to avoid cold start effects. A comparative analysis between nucleation and accumulation particle mode concentration, particle size distributions and a geometric mean diameter calculation are presented in this paper. In this sense, a reduction in the range of particle diameter emitted and a decrease in accumulation particle mode concentration with Fischer Tropsch fuel during the EUDC were found. In contrast, all biofuels used show an increase of particle number concentration in nucleation-mode during the urban cycles (ECE-15) related to combustion damage at low load conditions. Finally, an increase in the sulfur content diesel fuel leads to an increase in the geometric mean diameter of particle size distribution related to the increase in accumulation particle concentration during the entire cycle.

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1. Introduction

The major source of air pollution comes from vehicles powered by combustion engines using fossil fuels [1]. This type of vehicles are commonly used for road, rail or sea transport, being diesel engines the most popular ones mounted on these vehicles [2].

Over the last decades, diesel engines have been increasing their sales sharply in world market [3]. In this sense, this is the most widely used engine type in the European Union due to the fact that it has lower specific fuel consumption than its gasoline counterparts [4]. Conversely, diesel engines exhibit both high particles and high nitrogen oxides emission due to the high injection pressures that are already developing and the high air-to-fuel ratio which is obtained during the combustion process [5]. Thus, the particle emission problem associated to this engine type has become very important because the morphology of these particles cause serious toxicological and environmental problems [6,7], such as asthma or cardiorespiratory diseases. These problems are caused by the fact that emitted particle diameters have been getting smaller; being these types of nanoparticles the most harmful to the airways [8].

Concerning these health problems, during the last years, the European Union has been increasing the reduction on particle emission limits. At first glance, soot mass emitted was limited [9] in order to more recently incorporate a limit on the number of

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Nomenclature

Abbreviations

AFR	air-to-fuel ratio
BP	BioPalm fuel
BR	BioRapeseed fuel
BS	BioSoybean fuel
D.7ppm	7 ppm sulfur content diesel
D.50ppm	50 ppm sulfur content diesel
DOC	diesel oxidation catalyst
DR	dilution ratio
DPF	diesel particulate filter
ECE-15	urban driving cycle
ECU	electronic control unit
ED	ejector diluter
EEPS	engine exhaust particle sizer
EUDC	extra urban driving cycle
FPS	fine particle sampler
FT	Fischer Tropsch fuel
GMD	geometric mean diameter
GTL	gas to liquid fuel process
HP-EGR	high pressure exhaust gas recirculation
HSDI	high speed direct injection
LSD	low sulfur diesel
NEDC	New European Driving Cycle
PTD	porous tube diluter
PSD	particle size distribution
SOF	soluble organic fraction
TPER	total particle-energy ratio
ULSD	ultra low sulfur diesel

particles that are expelled into the atmosphere [10]. For this purpose, a growing interest of the scientific community in order to research methods or alternatives to reduce the particulate emissions by incorporating particulate filters [11,12], improvements in the combustion process [13], exploring injection parameters [14], optimization of combustion chamber geometry [15] or varying the position of aftertreatment systems [16] have been showed in a recent years.

Another attracting area increasing the scientific interest is the use of biofuels or alternative fuels [17] as a substitute of fossil fuels, being biodiesel widely used as alternative fuel for internal combustion engines [18]. This is due to its advantages, especially environmental improvements [19,20]. Biodiesel fuels are known to reduce engine exhaust emissions [21], being the reduction in gaseous emission confirmed by diverse authors [22–24] so it appears as a good sustainable alternative to the depletion of fossil stocks. Its main advantage is that they are environmentally friendly fuels and have a 100% pure renewable origin [25].

As an alternative to biodiesel, other fuels currently used in diesel engines are synthetic oils obtained through Fischer Tropsch process [26], which are considered as an interesting substitute of diesel fuel. Fischer Tropsch process is a chemical process for the production of liquid hydrocarbons from synthesis gas (GTL) (CO and H_2) [27,28] when natural gas is the raw material. The absence of aromatic compounds favors reduction of particle matter and NOx formation due to the high cetane number related to paraffinic structure [29], which would improve the NOx-PM trade off in diesel engines [30].

Although a number of works have assessed the effect of fuel formulation on gaseous emission in transient conditions, but not on determining the influence of fuel formulation on particle size distributions [31]. Moreover, the few published studies concerning particle size distribution have been primarily based on the evaluation of the effects of fuel formulation during stationary operating conditions [32], being certain published works [33,34] centered in particle emission analysis but just referred on the evaluation of total particles emitted.

This paper is presented in order to explore the effect of fuel formulation on the particle size distribution during transient operating conditions. Six alternative fuels were tested in a diesel engine providing the difference on particle emission when dynamic conditions are applied. In this sense, the objective of this paper is to make an exploration of the effects of different fuels formulation in terms of particle size distribution (PSD) and particle emission during the assessment of New European Driving Cycle (NEDC).

2. Material and methods

2.1. Experimental setup

This study was performed in a 2-l, 4-cylinder, high-speed direct injection diesel engine (HSDI) for passenger car applications. The engine was equipped with a high-pressure loop exhaust gas recirculation system (HP-EGR) and a high-pressure fuel injection pump using a common-rail injection system. The main engine characteristics are given in Table 1. For all experimental test, original fuel injection, turbocharging and exhaust gas recirculation strategies were applied in the entire range of engine performance.

The engine was connected to an AC dynamometric brake, which allows instant engine speed and torque control until 250 kW. For engine operation, the Engine Control Unit (ECU) was fully accessible and it could be operated through the ETAS-INCA software being the engine fully equipped with K thermocouples and pressure sensors in the exhaust, cooling, intake and lubrication systems.

In order to obtain accurate measurement, fuel consumption was determined by two methods. Firstly, a gravimetric system AVL-733S Dynamic Fuel Meter was used. Since the response time of AVL-733S was too long for transient operation, fuel consumption signal provided by the ECU was calibrated in steady state operating conditions, and then used as a second fuel consumption measuring system [35]. For air mass flow rate measurement at the intake manifold, a Sensyflow-P Sensycon hot-plate anemometer system was used.

For particle emission measurement, a TSI-Engine Exhaust Particle Sizer (EEPS) spectrometer was used in order to obtain fast response in particle size distribution measurements during dynamic cycles [36]. EEPS is capable to measure particle size distribution at a sample-rate of up to 1 Hz providing a measurement range between 5.6 and 560 nm. The measurements were taken downstream the diesel oxidation catalyst (DOC) and before the

Table 1
Engine main characteristics.

Type	4-cycle
Displacement	1998 (cm^3)
Diameter	85 (mm)
Stroke	88 (mm)
Number of cylinders	4 (–)
Valves per cylinder	4 (–)
Compression ratio	18:1 (–)
Maximum power	100 (kW) at 4000 rpm
Maximum torque	320 (N m) at 1750 rpm

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