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Particle Number and Size Distribution from a Small Displacement Automotive Diesel Engine during DPF Regeneration

2010-01-1552
Published
05/05/2010

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ABSTRACT

The aim of this work is to analyze particle number and size distribution from a small displacement Euro 5 common rail automotive diesel engine, equipped with a close coupled aftertreatment system, featuring a DOC and a DPF integrated in a single canning. In particular the effects of different combustion processes on PM characteristics were investigated, by comparing measurements made both under normal operating condition and under DPF regeneration mode.

Exhaust gas was sampled at engine outlet, at DOC outlet and at DPF outlet, in order to fully characterize PM emissions through the whole exhaust line. After a two stage dilution system, sampled gas was analyzed by means of a TSI 3080 SMPS, in the range from 6 to 240 nm. Particle number and size distribution were evaluated at part load operating conditions, representative of urban driving.

Finally, particle number and size distribution at engine outlet were also evaluated fuelling the engine with neat FAME (Fatty Acid Methyl Ester), in order to evaluate the impact of alternative fuels on PM characteristics during normal operating conditions.

Results show that under normal operating conditions the engine and DOC outlet particle number and mass size distributions appeared to be extremely similar, while the DPF exhibited high values of filtration efficiency on a particle number basis also in the nanoparticles range.

Regeneration mode caused a particle number increase of an order of magnitude, with a substantial shift of the number distribution peaks towards larger diameters. The particle number across the DOC showed a remarkable reduction for particles larger than 40nm, with one order of magnitude reduction in concentrations.

Fuelling the engine with FAME leads to a remarkable reductions both in terms of particle number and mass (up to 80% and 90% respectively) under normal operating conditions.

INTRODUCTION

Although diesel engine emission regulations throughout the world have always been based on gravimetric methods for the PM measurement, there is increasing concern about PM health and environmental effects base on the number of particles. There is alarm that reductions in PM mass which could be achieved through engine and aftertreatment measures were not always accompanied by decreases in total particle number and surface area. This has led to the introduction of new PM limits in terms of particle number [1] and has raised a growing interest among researchers about particle number and size characteristics, especially as far as engines equipped with Diesel Particulate Filters (DPF) are concerned [2,3,4,5,6].

The aim of this work is therefore to collect further information about particle number and size emissions from a small displacement Euro 5 common rail automotive diesel engine, equipped with a close coupled aftertreatment system, featuring a DOC and a DPF integrated in a single canning.

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especially during regeneration events at low engine speeds and loads, representative of urban driving conditions.

Finally, due to the growing interest in alternative fuels for diesel engines [7,8,9,10,11,12], the impact of a biofuel on PM characteristics was also evaluated, by fuelling the engine with neat FAME (Fatty Acid Methyl Ester).

EXPERIMENTAL SET-UP

The experimental tests were carried out at the ICE Advanced Laboratory of Politecnico di Torino on the test rig shown in Fig. 1a, which is equipped with an eddy current dynamometer connected to a passenger car turbocharged Common Rail DI Diesel engine, the main characteristics of which are listed in Table 1. The engine is equipped with a close coupled aftertreatment system, featuring a DOC and a catalyzed DPF integrated in a single canning, the main features of which are shown in Table 2. Exhaust gas was sampled at engine outlet downstream of the turbine, at DOC outlet and at DPF outlet, in order to fully characterize particle numbers and sizes through the whole exhaust system.

Tests were performed fuelling the engine with ultra low sulfur diesel fuel compliant with Directive 2003/17/EC (S content < 10mg/kg).

Table 1. Main characteristics of the test engine

Engine Type	Diesel 4 stroke
Displacement	1248 cm3
Cylinders arrangement	4 in line
Max Power	55 kW @ 4000 rpm
Bore x Stroke	69.6 mm x 82 mm
Compression Ratio	16,8 : 1
Turbocharger	Single-stage with waste gate
Fuel injection system	Common Rail

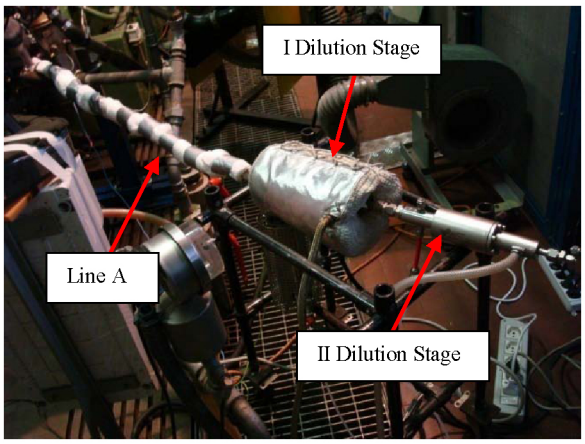


Figure 1a. Experimental test rig: two stage dilution system

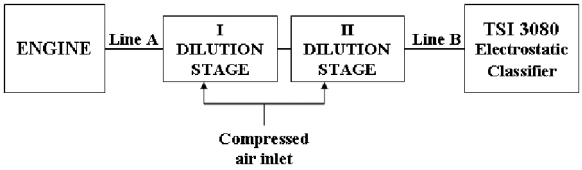


Figure 1b. Sketch of the dilution system

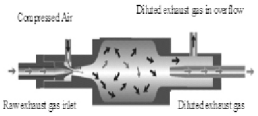


Figure 1c. First dilution stage scheme (adapted from Dekati Ltd).

Table 2. Main characteristics of the aftertreatment system

	DOC	DPF
Material	Cordierite	SiC
Cell density [cpsi]	400	300
Substrate volume [dm3]	1.1	2.6
Substrate length [mm]	76.2	177.8
Wall Thickness [mil]	4.5	10

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Figure 1b shows the sampling system scheme and its characteristics. The sampling system consists of two dilution stages connected to a TSI 3080 SMPS. A first sampling pipe, namely Line A, made of an heated and insulated inox pipe, connects the sampling point to the first dilution stage (first dilutor of a DEKATI DI-2000 package), which is heated at 250 °C to avoid nucleation [13]. In the first dilution stage filtered compressed air heated to 150 °C flows through an orifice placed on the sample flow axis as shown in Figure 1c. To obtain a higher dilution ratio a second dilution stage was then used (second dilutor of a DEKATI DI-2000 package). The second stage is not heated and it is directly connected to the TSI 3080 SMPS by means of flexible pipe (line B in figure 1b). A total dilution ratio higher than 60 was achieved, that should reduce particle agglomeration according to [13,14,15].

At the end of the above described sampling system exhaust gases reach the TSI 3080 SMPS (refer to [14] for a detailed description of the operating principle), which is composed by:

- Electrostatic classifier TSI 3080 with a Kr-85 Bipolar Charger using Kripton as ion source
- Inlet impactor 1035900
- Differential mobility analyzer TSI 3081
- Condensation particle counter TSI 3025A

Exhaust gases were also sampled at the engine outlet by means of a Fisher-Rosemount NGA-2000 gas analyzer for the measurement of the gaseous emission; furthermore an AVL 415S smoke meter for the measurement of the particulate filter smoke number FSN was also used for repeatability checks.

In-cylinder pressure was acquired by means of piezoresistive pressure transducers integrated in the glow plugs: pressure signals were sampled by means of a 12-bit high-speed multichannel data acquisition system (National Instruments DAQCard-AI-16E4), coupled with a high-resolution (0.4°) crank angle encoder. Injectors command signals were also acquired by means of a Tektronix TCPA300 current probe.

PARTICLE SIZE AND NUMBER MEASUREMENTS

Particle number and size distribution were evaluated at part load both under normal operating conditions and under DPF regeneration mode, in order to highlight the impact of the different combustion process on PM characteristics. Two different engine operating conditions, 1750 rpm / 3.5 bar bmep and 1500 rpm / 2.2 bar bmep were selected, as representative of low load urban driving conditions, which can be critical as far as the DPF regeneration is concerned. During normal operating conditions at low load the injection pattern usually shows one pilot injection, followed by the main injection (see Figure 2, top), while under DPF regeneration mode the main injection pulse is delayed and is then closely followed by an after injection, plus an additional post injection which usually takes place at the end of the exhaust stroke, as shown in Figure 2 (bottom).

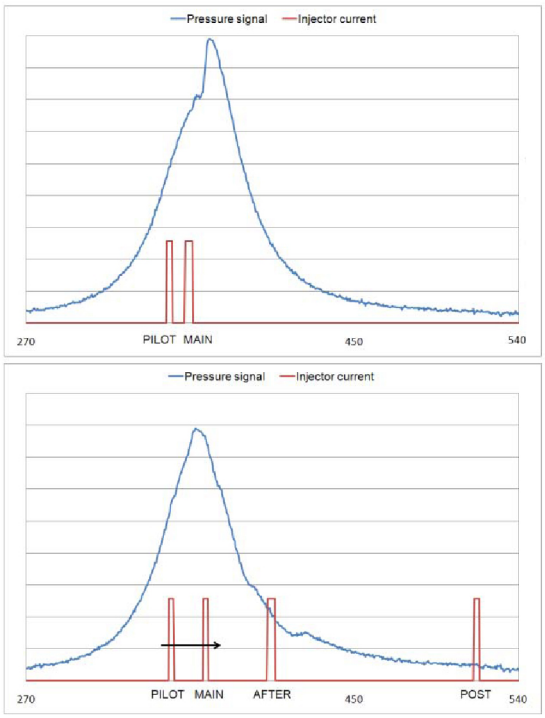


Figure 2. Injection strategies during normal engine operating conditions (top) and during DPF regeneration (bottom).

While the delayed main injection along with the after injection allows an increase of the engine exhaust temperature up to about 300 °C even at the low load tested operating points, the post injected fuel is mainly burned across the DOC (as its high HC conversion efficiency suggests), thus raising the DPF inlet temperature above 600°C and allowing the DPF regeneration, as shown in Figure 3.

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