CHEMICAL ENGINEERING TRANSACTIONS Volume 22, 2010
Editor Eliseo Ranzi

DOI: 10.3303/CET1022042

Ultrafine particle emission from modern diesel engines: effects of the egr and engine calibration

Beatrice, C.[1], Di Iorio, S.[1], Guido, C.[1], Fraioli, V.[1], Lazzaro, M.[1], Sirignano, M.[2]
[1]Istituto Motori – CNR, Viale Marconi, 8, 80125, Naples, Italy
[2]Department of Chemical Engineering, University of Naples Federico II, P.le Tecchio 80, 80125, Naples, Italy

In the last years increased interest in pollution control focused on the particulate emission from real combustion systems. These particles are usually not relevant for the total mass of particulate emitted, but become predominant in a concentration number analysis. Measurements have been conducted at the exhaust of an EURO5 diesel engine, in order to investigate the mechanisms of particle formation and the influence of combustion characteristics on particle size distribution in diesel engine combustion. Particles characterization has been performed upstream the particulate filter. In particular, it has been investigated the effect of EGR in three engine points representative of a low, medium and high load engine operative conditions. To investigate the effect of engine combustion, EGR has been varied from zero to a value comparable to the current EURO5 engine calibration.
A TapCon (or Vienna type) differential mobility analyzer (DMA), a differential mobility spectrometer (DMS) of Cambustion and an AVL Microsoot sensor have been employed to have a complete description of particle size distribution function (PSDF) and soot mass concentration at the exhaust of a real engine. Moreover gas analysis has been performed in all the operative conditions.
Focusing the attention in the size range 1-100nm, it is generally possible to distinguish two peaks in the particles size distribution function: the first peak is around 2-4nm, the second one is located at about 50-60nm. These two modes in the particle size distributions are present simultaneously in some combustion conditions, whereas in other cases only the second one is found. This behaviour suggests that the combustion condition can be responsible for the production of particles belonging to the first mode. So future high-EGR engine calibration for very low-NOx emission vehicles will require special attention in ultrafine particle emission control.

1. Introduction

Particle emissions from energy production systems have been pointed out to be an important concern for the impact on the human health and the environment

Please cite this article as: Beatrice C., Di Iorio S., Guido C., Fraioli V., Lazzaro M. and Sirignano M., (2010), Ultrafine particle emission from modern diesel engines: effects of the egr and engine calibration, Chemical Engineering Transactions, 22, 257-262
DOI: 10.3303/CET1022042

[Ramanathan et al., 2008; Li et al., 2003]. In particular the attention has been focused both on large scale production and on combustion devices as small as automotive engines.

Diesel engines are attractive in terms of performance and pollutants abatement; however they are still one of the most important sources of particulate and NOx emissions, especially in urban areas [Collings et al., 2000].

According to the studies conducted on laboratory systems, particles in the ultrafine range have been pointed as major responsible for pollution and the consequent effect on the thermal balance of the Earth. Moreover their small size allows them to deeply penetrate into the respiratory system representing a serious health risk [Oberdörster et al., 2002].These particles are not usually relevant for the total mass, but become predominant in a concentration number analysis [Kittelson 1998].

Particle production can be strictly linked to combustion conditions. In order to better understand the mechanisms that lead to inception and growth of particle in diesel engine, several engine conditions have been investigated.

Measurements have been conducted at the exhaust of an EURO5 diesel engine, sampling the particles upstream the particulate filter, in order to investigate the mechanisms of particle formation and the influence of combustion characteristics on particle size distribution in diesel engine combustion.

To have more information on particle features several techniques have been used. A TapCon (or Vienna type) differential mobility analyzer (DMA) and a DMS Cambustion, that furnishes the particle size distribution of particles, have been coupled with a Microsoot sensor, that measures soot mass concentration, to have a complete overview of particulate matter produced. For each engine load condition (low-medium-high load), the tests have been conducted varying the EGR from zero to an optimal value able to approach EURO5 requirements. In this way, an evaluation of the current status of the PSDF for the most advanced diesel engines, and the possible future incoming issues from the use of high-EGR engine calibration have been checked.

2. Experimental Set Up

A TapCon (or Vienna type) differential mobility analyzer (DMA) equipped with a Faraday Cup Electrometer (FCE) has been used for the characterization of the particles size distribution functions. The DMA, in the adopted configuration, allows to measure particles down to 2nm and up to 100nm. The Cambustion differential mobility spectrometer (DMS500) detects particles in the size range from 5nm up to 1000 nm: its measurement principle is based on the deflection of electrically charged particles, combined with electrical counting. Moreover a 483 Microsoot sensor has been employed to measure the soot mass concentration. Thermodynamic conditions and the main gaseous pollutant species concentration in the exhaust have been also measured.

The sampled stream has been diluted by using a DEKATI ® Diluter, which allows to obtain a dilution ratio around 1:10 by means of an ejector nozzle. The dilution system is fundamental in order to avoid condensation in the sampling line of water or other hydrocarbons and incorrect measurement of particle size distribution function due to coagulation.

Measurements have been performed at the exhaust of the FIAT 1.9 liter MultiJet a four-stroke turbocharged Common-Rail (CR) Diesel engine, whose main characteristics are reported in Table 1. Its displacement represents the most popular size of Diesel engine for passenger cars in the European market.

Table 1 Main features of the engine

Engine type	CR MultiJet In-line 4 cylinders 16valves
Bore [mm] x Stroke [mm]	82.0 x 90.0
Compression Ratio	16.5
Displacement [cm3]	1910
Valves per cylinder	4
Injector	Bosch CRIP 2.2, 7 holes
Catalyst system	Closed-couple DOC plus underfloor DPF
Maximum Power	112 kW @ 4200 rpm

The engine is equipped with an open Engine Control Unit (ECU) connected to a PC to monitor and control all engine parameters such as the injection strategy and the EGR rate. Further details on the engine layout can be found in [Beatrice et al., 2009]. The effect of EGR was investigated in three different engine operating conditions passing from zero to map value.
The operating conditions are reported in Table 2.

Table 2 Engine operating conditions

	Engine speed [rpm]	**BMEP [bar]**	**SOIPilot [cad BTDC]**	**SOImain [cad BTDC]**	**Prail [bar]**	**EGR [%]**
L1	1500	2	16	0.5	350	0
L2	1500	2	17	1.5	350	38
M1	2000	5	25	2.0	766	0
M2	2000	5	26	3.3	766	26
H1	2500	8	30	3.5	1124	0
H2	2500	8	33	6.0	1124	20

3. Results and Discussion

In Figure 1a particle size distribution function measured with DMA in low load engine condition is reported. Focusing the attention in the size range 1-100nm, it is generally possible to distinguish two peaks in the size distribution function of the particles: the first peak is around 2-4nm, the second one has the maximum at 50-60nm [Kittelson, 1998]. In the low load condition these two modes are present simultaneously.

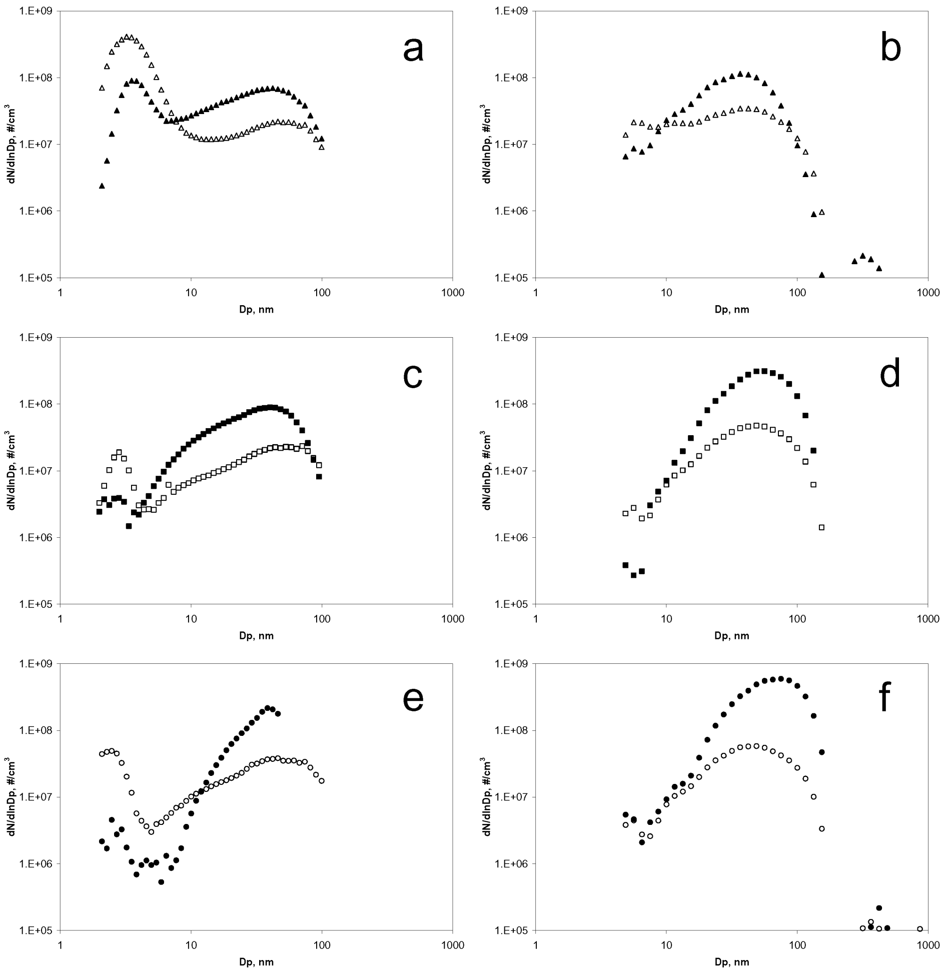

Fig.1 PSDF measured with DMA (a,c,e) and DMS (b,d,f) at the exhaust manifold in different combustion conditions: L1 (Δ), L2 (▲), M1 (○), M2 (●), H1 (□), H2 (■).

However, when the EGR is set in the optimal EURO5 condition, it considerably reduces the number of particles smaller than 10nm, whereas the total amount of particulate increases. The same effect is obtained in medium and high load condition in Fig 1c and 1e, although the second mode does not change in terms of the size of the peak value. Particle size distribution functions measured with Cambustion (Fig 1b, 1d and 1f) confirm the effect of EGR on the large particles, whereas the ones smaller than 5nm are below the detection limit of the instrument.

The effect of EGR on the total soot concentration is shown in Fig. 2 (top), where Microsoot soot mass concentration data are reported.

In Fig. 2 (bottom) unburned hydrocarbons, nitrogen oxides and carbon monoxide concentrations in the exhaust gas are reported, to further evidence the EGR effect over combustion efficiency. In particular EGR leads to lower combustion temperature, a considerable increase in HC and total soot mass concentration and a strong reduction of

NOx. The different combustion conditions affect both the high temperature formation of first mode particle and the condensation process occurring in post oxidation zone [De Filippo 2008; Fraioli, 2008].

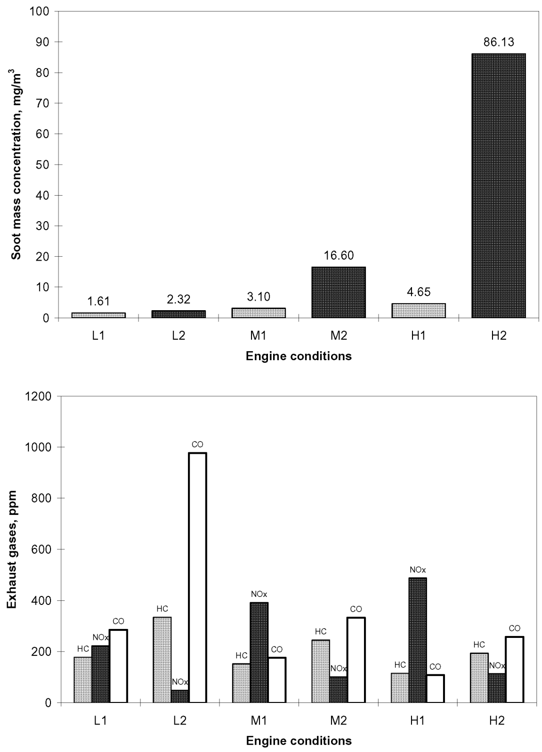

Fig.2 Soot mass concentration measured with Microsoot sensor (top) and gases (bottom) at the exhaust manifold in different combustion conditions.

Moreover, previous studies [Kittelson et al., 1998; Desantes et al. 2005] correlate the reduction of 10nm particles to the increased adsorption or condensation of volatile materials on the particles surface, prevailing over the nucleation rate. On the other side deeper investigations are necessary to better understand the EGR effect on this first mode.

The engine load seems to have an effect similar to EGR on particles production: the higher is the engine load, the lower is the first peak value and the unburned gases; on the contrary, a higher engine load produces much more particulate matter and NOx. The effect on the emissions appears evident, whereas the causes can be again related both to change in in-cylinder temperature and increased condensation rate in post oxidation zone.

4. Conclusions

Some preliminary investigations on the correlation between diesel combustion conditions and the particle size distribution function of the emitted nanoparticles are reported in the present paper. EURO5 EGR calibration leads to a decrease of nuclei particles and an increase in the particles number of the accumulation mode. Analogous results are observed increasing engine speed and load.
Further investigations will be performed in order to better analyze the formation process of the nuclei particles. More in detail, the operative conditions effect on particles emission will have to be taken into account in view of the future EURO6 diesel engines calibration, characterized by the adoption of premixed combustion and high EGR level. In addition, the capability of the ultrafine particles emission control at the engine exhaust has to be evaluated also according to the efficiency of the future DPF devices.

References

Beatrice C., Bertoli C., Del Giacomo N., Guido C., 2009,Experimental Investigation of the Benefits of Cooled and Extra-cooled Low-Pressure EGR on a Light Duty Diesel Engine Performance, SAE Paper 2009-24-0126

Kittelson D.B., 1998,Engines and Nanoparticles: A Review, J. Aerosol Sci. 29 575–588.

De Filippo A., 2008, Characterization of Carbonaceous nanoparticles size distribution (1-10nm) emitted from laboratory flames, diesel engines and gas appliances, PhD thesis Department of Chemical Engineering: University of Naples.

Desantes J.M., Bermúdez V., García J.M., Fuentes E., 2005, Effects of current engine strategies on the exhaust aerosol particle size distribution from a Heavy-Duty Diesel Engine, Aerosol Science 36 1251–1276.

Fraioli V., 2008, Autoignition and particles formation in diesel engines: modeling and experiments. Department of Chemical Engineering: University of Naples.

Kittelson D. B., Watts W. F. & Arnold M., 1998, Review of Diesel Particulate Sampling Methods, Department of Mechanical Engineering: University of Minnesota.

Li N., Hao M., Phalen R. F., Hinds W. C., Nel A. E., 2003, Particulate Air Pollutants and Asthma. A Paradigm for the Role of Oxidative Stress in PM-Induced Adverse Health Effects, Clinical Immunology, 109, 250–265.

Collings N., Graskow B.R., 2000, Particles from Internal Combustion Engines - What We Need to Know, Physical and Engineering Sciences, 358, pp. 2611-2623.

Oberdörster G., Utell M. J., 2002, Ultrafine Particles in the Urban Air: to the Respiratory Track and Beyond, Environmental Health Perspectives, 110, 440–441

Ramanathan V., Carmichael G., 2008, Global and Regional Climate Changes Due to Black Carbon, Nature Geoscience, 1, 221–227.