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REVIEW ARTICLE

Future European emission standards for vehicles: the importance of the UN-ECE Particle Measurement Programme

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Abstract

Traffic-related emissions of fine particles represent one of the main sources of air pollution especially in urban areas. In particular, diesel engines are blamed as one of the main contributors for their inherent high particulate emissions. In order to reduce the impact on human health of particulate emissions from vehicles, new stricter emission standards were considered necessary for Europe. The introduction of very low particulate emission limits has required the development of an improved measurement procedure for particulate mass and a new measurement procedure for particle number. The Particle Measurement Programme (PMP) was established in 2001 on the initiative of some European states to achieve this target. The interlaboratory comparison exercise for light duty vehicles, co-managed by the Joint Research Centre (JRC) of the European Commission and the UK Department of Transport, was completed in 2007, and the results have provided the scientific basis for the new Euro 5/6 limits for particle number and particulate mass. The heavy-duty interlaboratory exercise was started in the second half of 2007 with an exploratory work carried out at the JRC and is still on-going.

Keywords: *Exhaust emissions; particles; particle number; particulates; PM; vehicles; emissions standards; European Commission; Particle Measurement Programme*

Introduction

There is increasing concern about the significant risk to human health and environment which results from air pollution. Although air quality has improved over the past decade thanks to the measures already introduced to curb pollutant emissions, there are still significant air quality problems throughout the European Union, especially in urban areas and in densely populated regions. Road transport is one of the major sources of pollutant emissions and one of the main contributors to air pollution. Airborne particulates and ozone are the pollutants from road transport of most concern for human health (European Commission 2005a). The transport sector (including road transport, shipping, aviation and rail) accounted for 29% of total $PM_{2.5}$ emissions in the year 2000 (European Commission 2005b). The CAFE Programme has forecast the likely levels of air pollution given present policies for the period 2000–2020. Despite the improvements in pollutant emissions, health impacts from air pollution across the EU are still projected to be considerable in 2020. For particulate matter, the average loss in statistical life expectancy will be 5 months in 2020. Correspondingly, in 2020 it is estimated that some 2.5 million life years will be lost in the EU-25. This is equivalent to about 272 000 premature deaths (European Commission 2005a).

In order to achieve a significant improvement of air quality and to reduce the impact of particulate matter on human health a stricter emission limit, forcing the use of the best available technology to control PM emissions from vehicles, was deemed necessary and proposed by the European Commission. The new Euro 5/6 emission standards for light duty vehicles were approved by the

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European Parliament and the Council in December 2006 (European Parliament and Council, Regulation EC No. 715/2007). The new Regulation introduces a mass limit of 5 mg km^{-1} for particulate emissions and a new limit for particle number to be defined on the basis of the results of the Particle Measurement Programme (PMP). More recently, a new Regulation (European Commission, Commission Regulation No. 692/2008) implementing and amending Regulation No 715/2007, has set the value of the new limit for particle number (6×10^{11} particles km^{-1}). The new standards will force the manufacturers to install very efficient particulate filters on light duty diesel vehicles. The diesel particulate filter (DPF) is an after-treatment technology which has proved to be very effective in reducing particulate emissions from internal combustion engines. The abatement efficiency is usually very high, well above 90% for the closed filter type. Fitting this device to a diesel engine results in very low or even near zero particulate emissions.

The Particle Measurement Programme (PMP)

As the existing mass-based particulate measurement technique is not considered reliable at very low emission levels, a research programme named the Particle Measurement Programme (PMP) was established in 2001 on the initiative of some European states with the objective of developing a worldwide harmonized procedure for the measurement of particle number in engine exhaust gas and an improved mass-based measurement procedure. This was considered essential for the introduction of new emission standards forcing the use of very efficient DPFs.

The PMP project is conducted in the framework of the United Nations ECE WP29 GRPE (Working Party on Pollution and Energy) and is managed by a UN-ECE Working Group (http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/pmp19.html) chaired by the UK Department of Transport. The PMP Working Group currently comprises Governments (France, Germany, Greece, Japan, Korea, Sweden, Switzerland, UK), International Institutions (European Commission), industry (associations of car and engine manufacturers, instrument manufacturers), national vehicle emission laboratories and research institutions.

The mandate of the PMP is: to develop new techniques to replace or complement particulate mass measurement for light and heavy duty type approval; and to provide data on the performance of different technologies, including DPF equipped vehicles, according to the new measurement procedures in order to set reasonable particulate emission limits.

The project was divided into three different phases. Phases 1 and 2, already completed, were devoted to the assessment of several sampling methodologies and measurement techniques. Phase 3, still on-going, consists of the validation of the candidate methodologies and techniques identified during the first two phases of the project.

Phases I and II

Phases I and II were focused not only on measurement techniques but also on sampling methodologies as sampling conditions have a huge impact on the physical characteristics of the particles emitted by a vehicle. The following methodologies and measurement techniques were evaluated:

Sampling and conditioning systems. Constant volume sampling (CVS) (+ secondary dilution), CVS + thermodenuder or thermodiluter, rotary dilution, raw exhaust.

Measurement techniques. Gravimetric (modified US 2007), Filter + chemical analysis, TEOM, Laser Induced Incandescence, QCM, Photoacoustic absorption, Coulometric, Photoelectric charging, Light extinction, Laser Light Scattering, Differential Mobility Spectrometer, Optical counter (CPC), Electrical Mobility, ELPI, Diffusion battery, Diffusion charger.

As a conclusion of the first two phases, two measurement procedures were recommended as candidate procedures. These were: (1) a filter mass method based broadly upon those currently used in Europe and the US and that proposed for the US for 2007 type approvals; (2) a particle number method using a particle counter, a defined size range and sample preconditioning to exclude semivolatile particles. The main characteristics of the two candidate procedures were the following:

Improved particulate mass measurement

- Dilute exhaust sampling with HEPA and HC filtered dilution air;
- Sharp-edged, open-ended probe;
- Cyclone preclassifier on the sampling line;
- Improved sample temperature control: 47 ± –5°C for ≥0.2 s;
- Improved (US 2007) filter holder;
- Deletion of back-up filter.

Solid particle number count

- Dilute exhaust sampling with HEPA and HC filtered dilution air;
- Cyclone preclassifier on the sampling line;
- Sample thermal conditioning: heated dilution, evaporation tube, cold dilution;
- Condensation particle counter 23 nm (50%) cut point.

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The proposed procedure for particle number measurement implies that only solid particles are counted while the volatile particles are eliminated in the evaporation tube. The decision of not including the volatile particles in the measurement of particle number was taken on the basis of their very high sensitivity to sampling conditions which would unavoidably result in a very poor repeatability. This choice was also the result of a compromise between the need of reducing the risk for human health associated to particulate emissions and the need for a simple and robust measurement procedure to be used for type approval and conformity of production testing.

Phase III

The Phase III of PMP is currently on-going and consists in the validation of the recommended methodologies and techniques identified during the previous two phases of the project. It was decided to run two separate validation exercises for light duty vehicles and for heavy duty engines.

The aims of the validation exercises are:

- To assess repeatability and lab to lab reproducibility of proposed techniques;
- To assess performance levels of different engine/vehicle technologies;
- To assess comparability of available measurement systems for particle number.

The validation exercise for light duty vehicles, named Inter-Laboratory Comparison Exercise (ILCE-LD), was managed by the Transport and Air Quality Unit of the Joint Research Centre of the European Commission jointly with the UK Department for Transport. The ILCE-LD started in 2004 and was completed in early 2007 with the publication of the final report (it can be found at http://ies.jrc.ec.europa.eu/365.html).

Ten international laboratories from EU, Japan, Korea and USA (California) participated in the ILCE-LD. A Euro 4 diesel vehicle equipped with a particulate filter named 'golden vehicle', was circulated among all the laboratories and tested for emissions according to the new measurement procedures developed within the PMP. Each laboratory had to use a 'golden system' for particle counting in addition to its own system. Moreover, a 'golden engineer' visited all the laboratories before the tests in order to ensure the correct implementation of the PMP measurement procedures. Each lab was also asked to test additional vehicles and systems for particle counting different from the golden system.

Figures 1 and 2 show the experimental set-up used in the ILCE–LD for particle number and particulate mass measurement. At the end of the ILCE-LD, a total of 15 vehicles had been tested including:

- Six diesel vehicles equipped with a diesel particulate filter (DPF);
- Six diesel vehicles not equipped with a DPF;
- Three gasoline vehicles with direct injection engine (G-DI);
- Conventional gasoline vehicle (MPI).

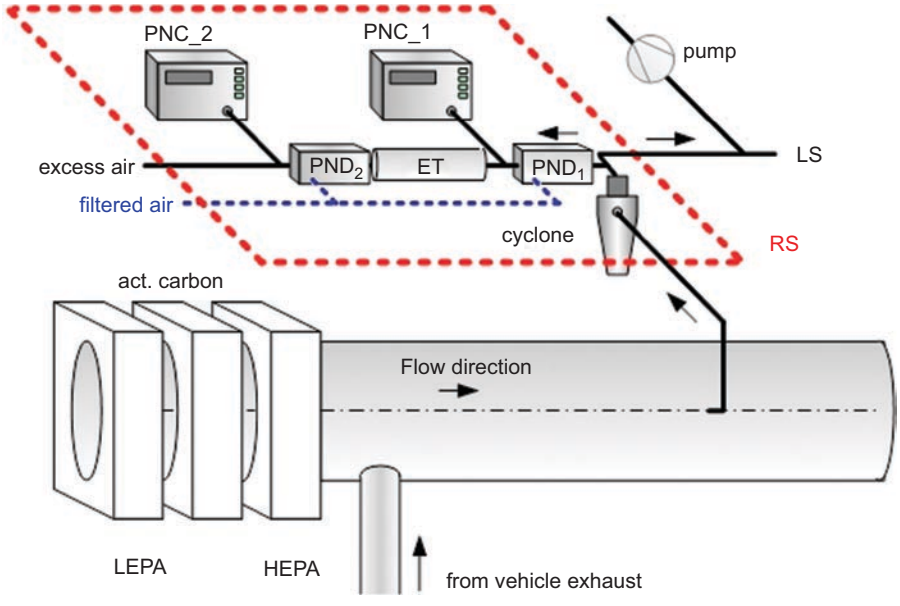

Figure 1. Experimental set up: 'golden' particle number measurement system.

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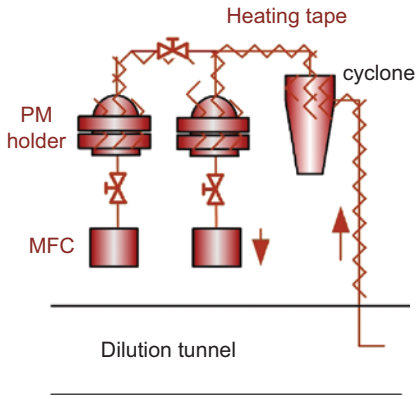

Figure 2. Experimental set up: modified mass method.

The results of the tests carried out in all the laboratories are shown in Figure 3 (particulate mass in mg km^{-1}) and in Figure 4 (particle number in particle km^{-1}). The golden vehicle is indicated with Au-DPF.

The main conclusions of the LD Inter-Laboratory Comparison Exercise are (Joint Research Centre 2007):

- The revised mass procedure shows good repeatability even on post-DPF measurement;
- Mass measurement insensitive to DPF fill state and DPF porosity;
- Mass measurement shows a 'repeatable zero', similar to tunnel background;

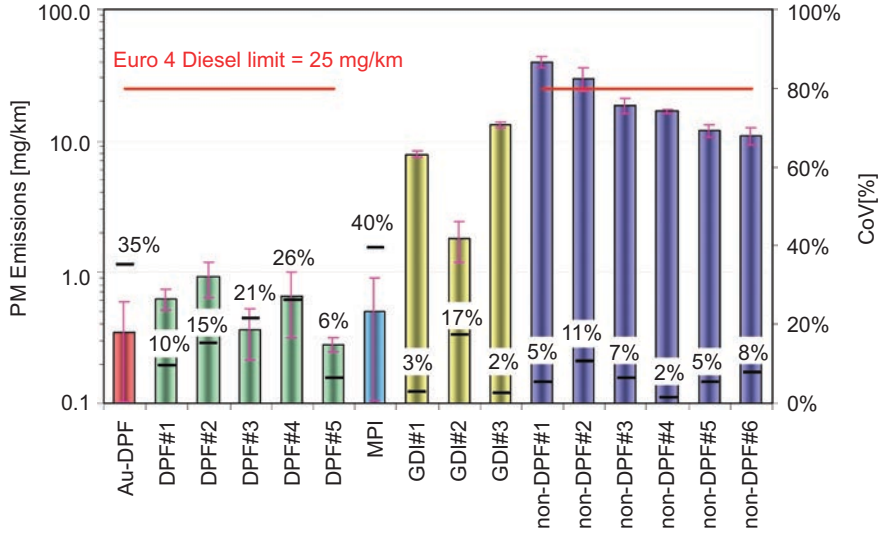

Figure 3. Particulate mass measured according to the PMP improved procedure.

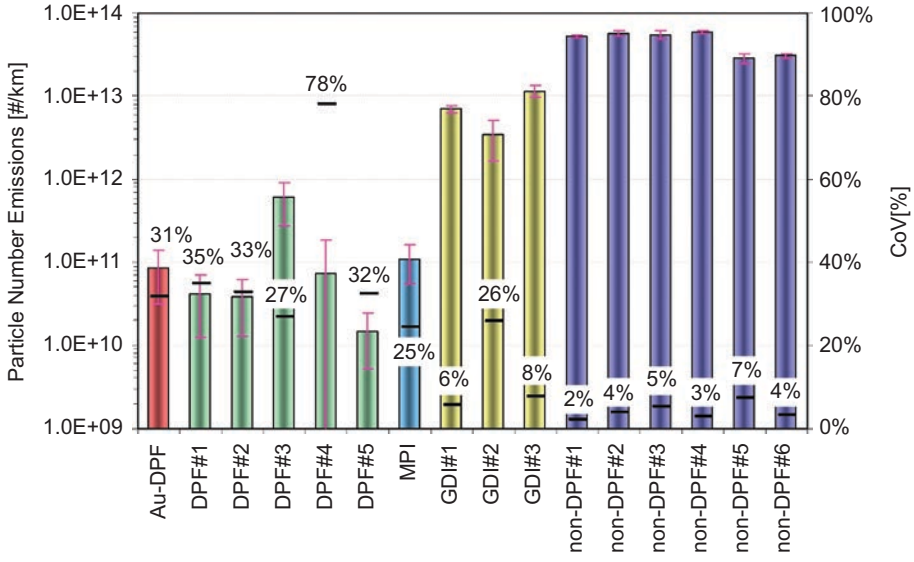

Figure 4. Particle number measured according to the PMP procedure.

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- Post-DPF mass is mainly volatiles while the mass of non-volatiles is <1/10 of the mass collected on the filter;
- Particle number shows good repeatability on DPF vehicles;
- Particle number can distinguish DPF fill state and porosity;
- DPF diesels emit $<10^{11}$ particles km^{-1}, similar to conventional petrols;
- Gasoline direct injection vehicles emit 10^{12}–10^{13} particles km^{-1};
- Non-DPF diesels emit ~$5x10^{13}$ particles km^{-1};
- These results have been used as the basis for the definition of the future Euro 5 and 6 particulate emission standards for light duty vehicles, shown in Table 1 (European Commission 2008, European Parliament and Council 2007).

A similar exercise is currently on-going with the objective of validating the measurement procedure for heavy duty engines. The JRC is also managing this exercise which consists of two in-parallel separate experimental activities: validation exercise and round robin.

The two exercises differ in their structure and target. The validation exercise aims to demonstrate the robustness, in terms of repeatability and reproducibility, of the particle number measurement procedure for heavy duty engines. For this purpose, a golden engine and two golden instruments will be circulated among several laboratories which will carry out a number of tests according to an agreed protocol (Joint Research Centre 2008). The round robin has the objective of establishing the repeatability of the procedure in more realistic conditions.

The validation exercise started in January 2008 and should be completed by January 2009. The round robin started in May 2008 and will last about 2 years.

Conclusions

In response to the increasing concern about the risk for human health due to airborne particulates, the European Parliament has approved the new Euro 5 & 6 emission standards for light duty vehicles which introduce much more stringent limits for particulate emissions. In particular a new limit for particle number has been set, complementing the already existing mass based limit. The new emission standards are expected to dramatically reduce particulate emissions from the next generation of light duty vehicles.

The new particulate limits have required a large research effort as new measurement procedures had to be developed. The new procedures have been developed within the PMP conducted in the framework of the UN ECE WP29 GRPE. The PMP has provided the technical basis for the definition of the Euro 5 & 6 particulate emission standards as well.

The programme has also shown that the cooperation between policy makers, industry and research institutes is fundamental for the development of shared and scientifically sound pieces of legislation.

Finally, the role of the JRC as a laboratory independent from any national or private interests has proved to be essential to provide unbiased technical and scientific support for the development of new European policies.

Table 1. Euro 4, 5 & 6 standards for particulate emissions.

	Mass of PM (mg km^{-1})		No. of particles (no. km^{-1})	
	Petrol[a]	Diesel	Petrol	Diesel
EURO 4	–	25	–	–
EURO 5	5.0/4.5[b]	5.0/4.5[b]	–	6.0×10^{11}
EURO 6	5.0/4.5[b]	5.0/4.5[b]	TBD[c]	6.0×10^{11}

[a]Positive ignition particulate mass standards shall apply only to vehicles with direct injection engines;
[b]a revised measurement procedure shall be introduced before the application of the 4.5 mg km^{-1} limit value;
[c]a number standard shall be defined before 1 September 2014.

Acknowledgements

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