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Evaluation of measuring methods for particle emission from modern diesel vehicles in periodic emissions control – Studies and Results

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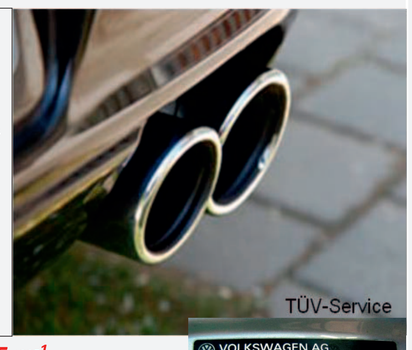
Introduction

As Work package 2 of the ENV02 PartEmission project (06/2011, to 05/2014) tree metrological institutions (PTB (GER), METAS (CH), MIKES (FIN)) and the JRC-IE evaluated measuring methods for periodic emissions controls of modern diesel vehicles. After the specification of consistent requirements for the novel measuring instruments a call of instruments were launched in March 2012 to approx. fifty European manufacturers and their associations for automotive emission testing instruments. Finally six manufacturers provided prototypes of their new developed instruments which were the following. Tree Light scattering instruments (L1, L2, L3) which were developed for the periodic emission tests according to the German VO 18-9. Two instruments which works with the diffusion charging principle (DC1, DC2) and are already commercially available for other applications and one Ionisation Chamber (IC) as an early stage prototype, basing on a house-hold smoke alarm detector, developed in the frame of a research program. All tested instruments were prototypes for this application. The evaluation of the instruments included laboratory tests, field measurements at the JRC-IE as well as user handling tests under service conditions. This work will establish the metrological background to support the efforts to bring the regulatory emission control equipment in line with the technical progress with regard to the recent advances in diesel after treatment technology. To enable trustable periodic emission control for modern diesel vehicles in the future.

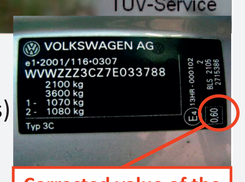
Tasks and Objectives

- Future procedures will have to cover emissions of conventional high-emitting diesel vehicles and DPF - equipped diesel vehicles (more than three orders of magnitude lower).
- If the purpose of a inspection check is to identify malfunctions of the emission control device, in particularly cracks in the DPF, different procedures may be appropriate for non-DPF- and DPF-equipped vehicles.

Range of limit values
from: 2010/48 /EU Annex II, 8.2.2
…
1. The level of concentration must not exceed the level recorded on the manufacturer´s plate
2. (b) Where this information is not available or requirements (a). do not allow the use of reference values, Maximum coefficient of absorption for:
— naturally aspirated diesel engines = **2,5 m $^{-1}$** ,
— turbo-charged diesel engines = **3,0 m $^{-1}$** ,
— a limit of **1,5 m $^{-1}$** shall apply to the following vehicles
(a) Light Duty Vehicle Diesel — Euro 4
(b) Heavy Duty Vehicle Diesel — Euro 4
(c) Heavy Duty Vehicle Diesel — Euro 5
(d) Heavy Duty Vehicle — EEV
….or put into service after July 2008….



Limit values from k=3.0 m^{-1} at least to k=0.5 m^{-1}



Corrected value of the absorption coefficient

•Evaluation of novel measuring instruments for periodic emissions control
- ➢Determination of technical requirements for novel instruments (prototypes)
- ➢Evaluation in laboratory tests

•Applicability of novel measuring instruments for periodic emissions control in field tests
- ➢Tests under controlled conditions similar to the type-approval testing
- ➢Tests under service conditions

Requirements for the laboratory tests

- ➢ DUT needs to be assessed through comparison to **Particle Number** and/or **Opacity-based** instruments.
- ➢ Checks should be performed over a large range of number concentrations and light extinction coefficients using a range of size distributions typical for light-duty diesel exhaust [b].
- ➢ Tested parameters should be sensitivity, linearity, size response, response to particles below 100 nm, response times, treatment to volatile particles

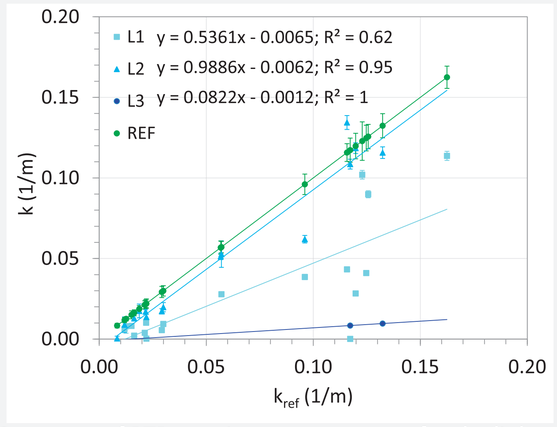
NMI	Aerosol type	Generator	Size		Number concentration (cm^{-3})	*Mass concentration ($\mu g\ m^{-3}$)	Absorption-coefficient (m^{-1})	Reference
			GMD[1] (nm)	MWSD[2]				
PTB	CAST	modified High mass CAST	50 – 240	1.6 – 2.2	$1.16 \cdot 10^7$ – $1.1 \cdot 10^8$	3000 – 380000	0.01 – 2.98	Opacimeter (AVL439)
METAS	CAST	Prototype CAST, homebuilt	23 – 200	1.4 – 1.7	$4.0 \cdot 10^4$ – $1.5 \cdot 10^6$	5 – 2800	Not measured	CPC , SMPS
MIKES	diesel soot	diesel soot generator, homebuilt	30 – 150	1.7 – 2.2	$6.0 \cdot 10^3$ – $1.0 \cdot 10^6$	156 – 721[3]	Not measured	CPC, grav. mass

[1] Geometric mean diameter (GMD) of the size distribution, 2 mean width of size distribution (MWSD), [3] Gravimetric measurements only at these mass concentrations, *for comparison

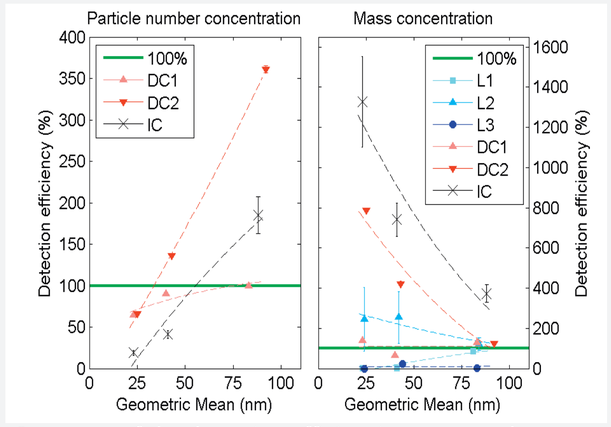
Specification of the reference aerosol used for the laboratory tests at the different NMIs

Selected results of the laboratory tests[c]

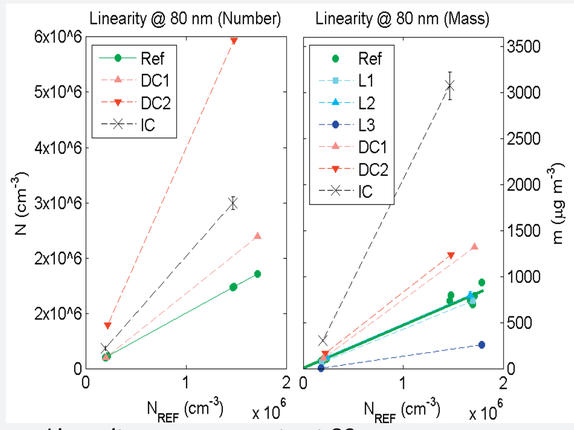
Many thanks to the manufacturers providing the instruments



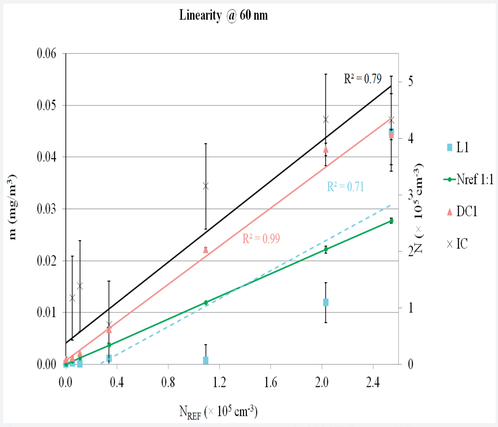
Summary of PTB opacity measurements for the light scattering instruments



Summary of the detection efficiencies measured at METAS



Linearity measurements at 80 nm performed at METAS using CAST aerosol.

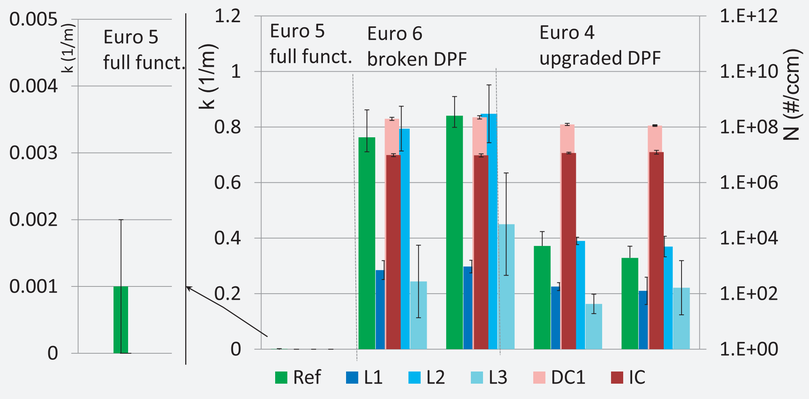


Linearity measurements at MIKES at 60 nm using diesel aerosol with low number concentration

Test under service conditions

The measurements were performed as usual periodic emission tests at DEKA, Stuttgart (Germany) with three different vehicles:

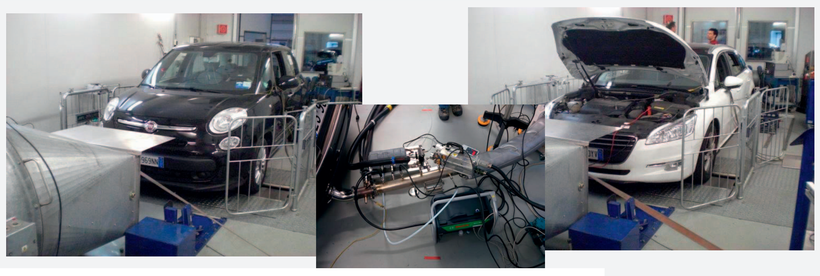
- Audi A4 (Euro5) with a full functioning DPF
- VW Passat (Euro6) with a broken DPF
- VW Multivan (Euro 4) with an upgraded DPF

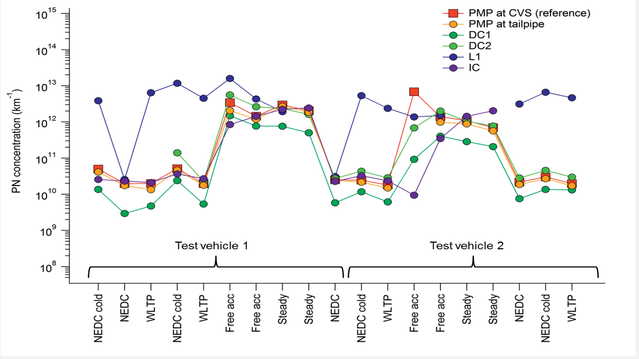


Response of the reference instrument (AVL 439. DEKRA, mean value of the peak absorption coefficient and the biggest difference between this single values, measuring mode ECE R24, EEC 72/306) and the instruments under test to the emitted particle concentration (primary vertical axis: absorption coefficient in m^{-1}, secondary vertical axis: particle/cm^3) of the test vehicles

Sampling performance during the practical usability tests at DEKRA, Stuttgart; single sampling tubes for each instrument were clamped on a extension tube behind the exhaust pipe

Field test in Vela1 at JRC-IE





Comparison of the distance specific PN emissions measured by the reference instrument (AVL Particle Counter PMP compliant at CVS), at tailpipe and the devices under test

Recommendation for the instruments manufacturers and for future legislation:
Functional checks should be carried out previous to any measurement in order to assure that the emission below the detection limit is due to the well functioning DPF and not due to failure of the instrument's sensor or sampling.

Conclusions

Future regulations regarding the periodic emission control for diesel vehicles should be based on opacity respectively particle number concentration (PN) measurements. The instruments under test are able to display the two measurands (L) or only PN (DC, IC) depending of the measurement principle. The results of the laboratory tests demonstrated that the **D**iffusion **c**harger as well as the **I**onization **c**amber was more sensitive to small particle sizes (below 70 nm) and very low concentrations (below $10^5 cm^{-3}$) than the **L**ight scattering instruments.
The tests under service conditions at DEKRA have shown that all tested measurement principles were able to detect DPF failures and the emissions of a Euro4 vehicle equipped with an upgraded DPF. The emitted particle concentration of the full functioning Euro 5 vehicle was too low to be detected by any instrument under test.
The outcome field tests according the type approval testing in Vela1 at JRC-IE with vehicles equipped with a full functioning aftertreatment system is that the emitted particle concentration of the Euro 5 vehicles during the high emission tests (free acceleration, according the periodic emission test) can be detected by all measurement principles but not by all instruments. The response of the Light scattering instruments were not detectable respectively don't correspond very well to the reference. Therefore, if the future approach in the periodic emission test should be the measurement of the particle concentration in the range of the values detected in the type approval, a complementary detector method (e.g. Diffusion charger or Ionisation camber) should be considered apart from the established opacimeter or its successor to meet the very low limit values.

[a] Mamakos, A., Krasenbrink, A. & Jordan-Gerkens, A., 2012. *Consistent requirements specified for novel measuring instruments (prototypes) and comparison with European legislative requirements,* s.l.: Report WP2 D1; ENV02 PartEmission.;
[b] geometric mean diameter of 50 to 100 nm and geometric standard deviation of 1.6 to 1.9 – from: Signature size distributions for diesel and gasoline engine exhaust particulate matter; Stephen J. Harris, M. Matti Maricq; Aerosol Science 32 (2001) 749-764;
[c] J. Spiegel, H. Andres, R. Högström, A. Jordan-Gerkens, A. Nowak, Laboratory evaluation of novel soot sensors for periodic emission control of modern diesel vehicles, Report WP2 D1.2; ENV02 PartEmission.

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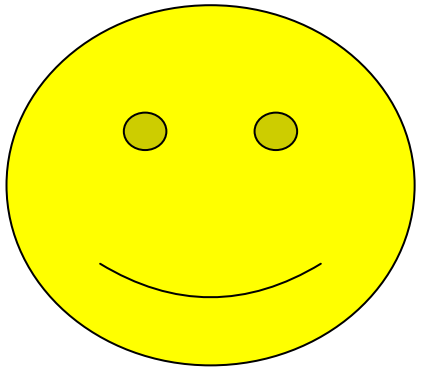

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