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Nanoparticle Emissions from Gasoline Cars DI & MPI

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Abstract

The nanoparticles (NP) count concentrations are limited in EU for Diesel passenger cars since 2013 and for gasoline cars with direct injection (GDI) since 2014. The limit for GDI was temporary extended to 6 x 10^{12} #/km (regulation No. 459/2012/EU). For the particle number (PN) of MPI gasoline cars there are still no legal limitations.

Nuclei of metals as well as organics are suspected to significantly contribute especially to the ultrafine particle size fractions, and thus to the particle number concentration.

In the present work some results of investigations of nanoparticles from five DI and four MPI gasoline cars are represented. The measurements were performed at vehicle tailpipe and in CVS-tunnel. Moreover, five variants of "vehicle – GPF" were investigated.
The PN-emission level of the investigated GDI cars in WLTC without GPF is in the same range of magnitude very near to the actual limit value of 6.0 x 10^{12} #/km. With the GPF's with better filtration quality, it is possible to lower the emissions below the future limit value of 6.0 x 10^{11} #/km.

The modern MPI vehicles also emit a considerable amount of PN, which in some cases can attain the level of Diesel exhaust gas without DPF and can pass over the actual limit value for GDI (6.0 x 10^{12} #/km). The GPF-technology offers in this respect further potentials to reduce the PN-emissions of traffic.

There is no visible nuclei mode and the ultrafine particle concentrations below 10mm are for both engine technologies GDI & MPI insignificant.

Some of the vehicles show at constant speed operation a periodical fluctuation of the NP-emissions, as an effect of the electronic control.

Tested vehicles

GDI

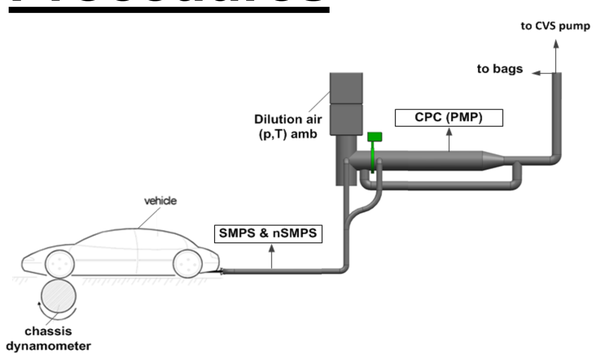
Vehicles ①②③	Volvo V60 T4F ①	Opel Insignia 1.6 EcoFlex ②	Mitsubishi Carisma 1.8 GDI ③
Number and arrangement of cylinders	4 / in line	4 / in line	4 / in line
Displacement cm³	1596	1598	1834
Power kW	132 @ 5700 rpm	125 @ 6000 rpm	90 @ 5500 rpm
Torque Nm	240 @ 1600 rpm	260 @ 1650 - 3200 rpm	174 @ 3750 rpm
Injection type	DI	DI	DI
Curb weight kg	1554	1701	1315
Gross vehicle weight kg	2110	2120	1750
Drive wheel	Front-wheel drive	Front-wheel drive	Front-wheel drive
Gearbox	a6	m6	m5
First registration	27.01.2012	2014	05.2001
Exhaust	EURO 5a	EURO 5b+	EURO 3
Aftertreatment	TWC	TWC	TWC/Ox.Cat

Vehicles ④⑤⑥	Opel Zafira Tourer ④	VW Golf Plus ⑤	Diesel Peugeot 4008 1.6HDi STT ⑥
Number and arrangement of cylinders	4 / in line	4 / in line	4 / in line
Displacement cm³	1598	1390	1560
Power kW	125 @ 6000 rpm	118 @ 5800 rpm	84 @ 3600 rpm
Torque Nm	260 @ 1650 - 3200 rpm	240 @ 1500 rpm	270 @ 1750 rpm
Injection type	DI	DI	DI
Curb weight kg	1678	1348 - 1362	1462
Gross vehicle weight kg	2360	1960 - 1980	2060
Drive wheel	Front-wheel drive	Front-wheel drive	Front-wheel drive
Gearbox	m6	m6	m6
First registration	22.07.2014	01.02.2010	12.04.2013
Exhaust	EURO 5b+	EURO 4	EURO 5b
Aftertreatment	TWC	TWC	DPF

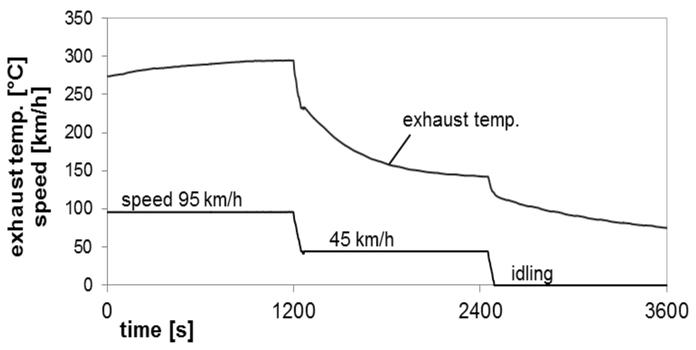
MPI

Vehicles ⑦⑧⑨⑩	Opel Adam ⑦	Fiat Panda 4x4 Twin Air ⑧	Ford KA 1.2i ⑨	Suzuki Baleno 1.2 Hybrid⑩
Number and arrangement of cylinders	4 / in line	2 / in line	4 / in line	4 / in line
Displace-ment cm³	1398	875	1242	1242
Power kW	64 @ 6000 min $^{-1}$	62.5 @ 5500 min $^{-1}$	85 @ 5500 min $^{-1}$	66 @ 6000 min $^{-1}$
Torque Nm	130 @ 4000 min $^{-1}$	145 @ 1900 min $^{-1}$	102 @ 3000 min $^{-1}$	120 @ 4400 min $^{-1}$
Injection type	MPI	MPI	MPI	MPI
Curb weight kg	1195	1170	989	1010
Gross vehicle weight kg	1465	1550	1320	1405
Drive wheel	Front-wheel drive	4x4	Front-wheel drive	Front-wheel drive
Gearbox	m5	m6	m5	m5
First registration	5.3.13	2.12.15	30.5.16	29.4.16
Exhaust	EURO 5b	EURO 6b	EURO 6b	EURO 6b
After-treatment	TWC	TWC	TWC	TWC + EGR

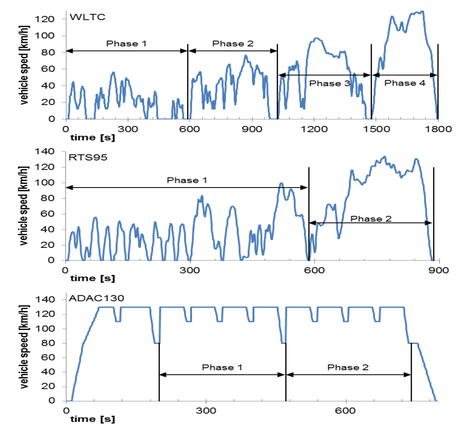
Procedures



Set-up of exhaust gas sampling for PN-analysis

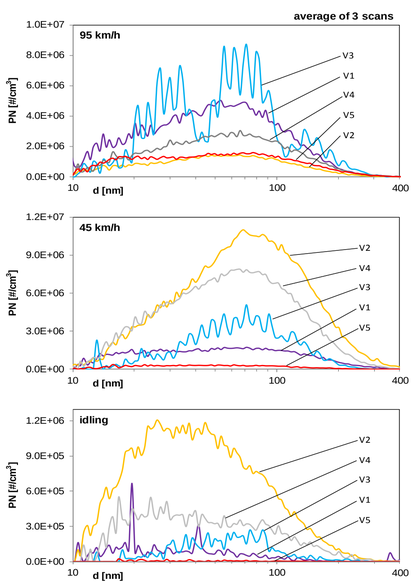


Steady State Cycle (SSC) and tailpipe temperature of vehicle 7 (MPI)

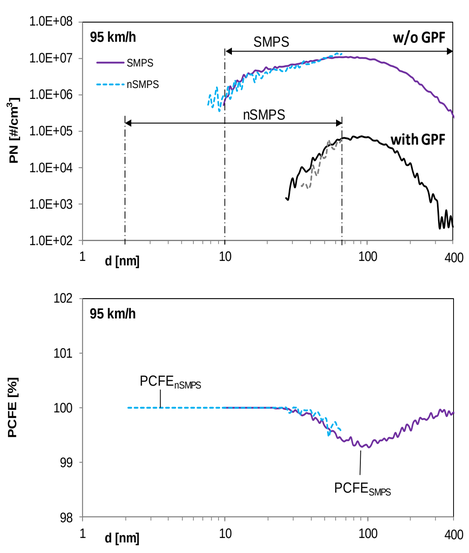


Transient driving cycles WLTC, RTS 95 and ADAC 130

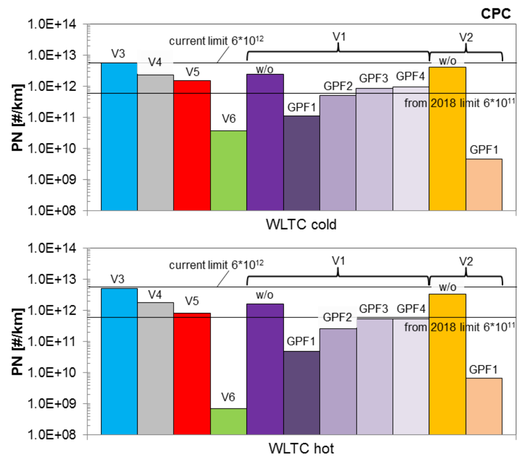
Resultats GDI



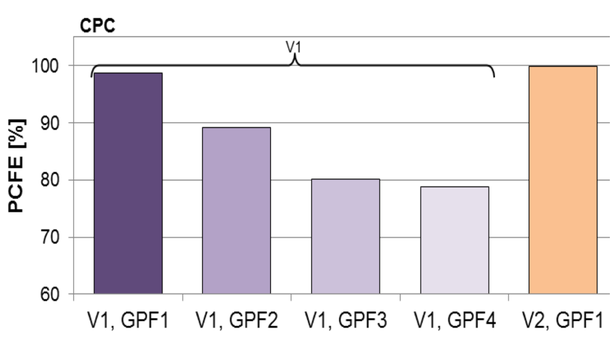
SMPS particle size distributions at constant speeds with different GDI vehicles (w/o GPF)



Example of PSD's with SMPS & nSMPS and particle counts filtration efficiency (PCFE) with V1, GPF 1 at 95 km/h

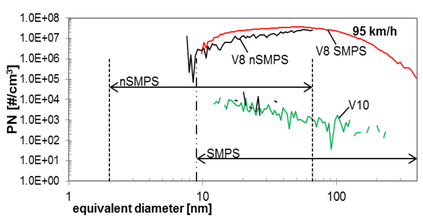


Comparison of PN-emissions in WLTC cold and hot for different vehicles

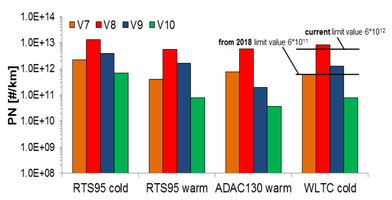


PCFE's of the investigated GPF's in WLTC hot

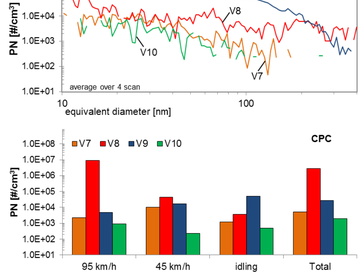
Resultats MPI



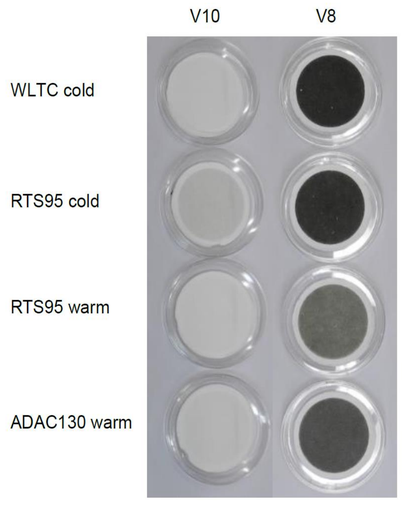
Particle size distribution of MPI vehicles (min/max emissions).



PN results in all driving cycles.



SMPS particle size distribution at constant speeds with different MPI vehicles.



Results of PM-results of the lowest & highest emitting vehicles in different transient cycles.

Conclusions

The most important statements of this work can be summarized as follows:

- The PN-emission level of the investigated GDI cars in WLTC without GPF is in the same range of magnitude and very near to the actual limit value of 6.0 x 10^{12} #/km.
- With the GPF's with better filtration quality it is possible to lower the emissions below the future limit value of 6.0 x 10^{11}#/km.
- The filtration efficiency of GPF can attain 99% but it can also be optimized to lower values – in this respect the requirement of "best available technology for health protection" should be considered.
- The present work demonstrated that the modern SI-vehicles with MPI also emit a considerable amount of PN and PM. In an extreme case the PN-emission was in the range of Diesel car (without DPF).
- The relationships of NP-emissions between different vehicles can vary depending on operating conditions.
- Generally there is a very good accordance of PSD's measured with both systems SMPS and nSMPS in the common size range (10-64 mm).
- For the investigated vehicles with gasoline DI and MPI, there is no increase of PC's in nuclei mode (below 10 nm) at the measured constant speeds, the particle counts below 10 nm are negligible.
- Due to the electronic regulation of the engine the NP-emission of some vehicles (here vehicle ③) are periodically fluctuating.

The present paper focuses solely on solid nanoparticle emissions. The tested GDI cars, except of vehicle ③, were with homogenous combustion concept and all of them (GDI & MPI) represented a modern TWC technology. According to that the emissions of gaseous legislated components (CO, HC, NO_x) were very low.
The present research on MPI vehicles, showed some tendencies of significantly increased PN-emissions. With this knowledge and taking into consideration the immense multiplication factor of MPI vehicles worldwide the legal PN-limitations for MPI should be quickly progressed.
The present high filtration quality of Diesel vehicles (DPF) set's high requirements on the filtration quality in the gasoline sector (GPF).

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