Road transport particle emissions characterization: focus on ultrafine particles

Ultrafine Particles: Science, Technology & Policy Issues, May 1, 2006
Contents

Based on the EU *Particulates* Research project activities, results and database ([http://lat.eng.auth.gr/particulates/](http://lat.eng.auth.gr/particulates/))

- Development of a measurement protocol to address both semi-volatile and solid particles
- Results from LDVs and HDVs
- Comparison of Diesel particle exhaust emissions from Light Duty vehicles and Heavy Duty engines
- Diesel Particulate Filter Efficiency
- Conclusions and follow-up
# The *Particulates* Consortium

## Partners

- Aristotle Univ. (GR) – Coordinator
- CONCAWE (B)
- Volvo (S)
- Tampere University (FIN)
- EMPA (CH)
- AEATechnology (UK)
- Institut Français de Pétrole (F)
- AVL (AUT)
- AVL-MTC (S)
- Graz Technical University (AUT)
- Aachen University (D)
- Joint Research Center (NL)
- VTT (FIN)
- Ford Research Center Aachen (D)

## Associate partners

- Renault (F)
- INRETS (F)
- Dekati (FIN)
- Stockholm Univ. (S)
- Athens Univ. (GR)
- TRL (UK)
- INERIS (F)
- LWA (UK)

## Consultants

- David Kittelson (USA)
- Georg Reischl (AUT)
Based on the EU *Particulates* Research project activities, results and database (http://lat.eng.auth.gr/particulates/)

- Development of a measurement protocol to address both semi-volatile and solid particles
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- Conclusions and follow-up
Motivation to Develop a Sampling System

- Primary aim was to develop a database with emission factors of several particle properties from various engine concepts and fuels and aftertreatment systems for evaluation of technology potential.

- Non-solid particles also of interest to understand their origin and occurrence.

- CVS not practical due to variance in sampling conditions. A dedicated sampling system was developed to establish the same sampling conditions in all laboratories, even over transient tests.
Typical Diesel Particle Size Distributions
Number, Surface Area, and Mass Weightings

Nuclei Mode - Usually consists of particles formed from volatile precursors as exhaust mixes with air during dilution.

Ultrafine Particles
Dp < 100 nm

Nanoparticles
Dp < 50 nm

Accumulation Mode - Usually consists mainly of carbonaceous agglomerates that have survived the combustion process.

Coarse Mode - Usually consists of re-entrained particles, crankcase fumes.

Fine Particles
Dp < 2.5 µm

PM10
Dp < 10 µm

Particulates dealt with both separately

Source: David Kittelson
Particulates Sampling System Schematic

Constant sample flowrate, constant sampling conditions regardless of particle source
Picture of Sampling System and Instrument Configuration

- Primary Dilutor
- CO₂ Analysers
- Mass Flow Controller
- CO₂ Calibration Gases
- CPC and DC
- SMPS and ELPI
- Mass Flow Controller and DGI
- Thermodenuder

At Shell Global Solutions
### Particle Properties Recorded in *Particulates*

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Property</th>
<th>Size resolution</th>
<th>Temporal resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensation Particle Counter (CPC)</td>
<td>Particle number concentration</td>
<td>One channel &gt;7 nm</td>
<td>1 s (transients)</td>
</tr>
<tr>
<td>Scanning Mobility Particle Sizer (SMPS)</td>
<td>Particle sizing and concentration</td>
<td>64 channels per decade 7-300 nm or 10-450 nm</td>
<td>90 s (steady states)</td>
</tr>
<tr>
<td>Electrical Low Pressure Impactor (ELPI) + thermodenuder (TD)</td>
<td>Solid particle sizing and concentration</td>
<td>First 8 channels considered with filter stage 7nm - 1 µm</td>
<td>1 s (transients)</td>
</tr>
<tr>
<td>Diffusion Charger (DC)</td>
<td>Active surface</td>
<td>One channel 7nm - 1 µm</td>
<td>1 s (transients)</td>
</tr>
<tr>
<td>Gravimetric Impactor (DGI)</td>
<td>Mass-based particle sizing</td>
<td>5 stages &lt;10 µm</td>
<td>Integral over a test</td>
</tr>
</tbody>
</table>
Selection of Sampling Conditions
Dilution Ratio (DR) & Dilution Air Temperature (DAT)

Change in number concentration for DR variation of 1 unit or DAT variation of 0.5°C

Vehicle: Skoda Euro II, Condition: 50 km/h, Load: 7 kW

Aerosol Science and Technology, 38:1149–1160, 2004
Selection of Sampling Conditions – Residence Time

Vehicle: **Euro 1 VW Golf**
Condition: **50 km/h**
Load: **7.6 kW**
DR: ~**25:1**, DAT: **22°C**
Primary Dilution Ratio Variation (Steady states)

DR map (Buffered system)

Engine: Euro 1 VW TDI
DR setting: 12,95:1 (1500 rpm, 25% load)

SAE paper 2004-01-1439
Round Robin Results (Between Lab Variability)

Regulated Pollutants & CO₂

Between laboratories COV

- PM
- NOx
- HC
- CO
- CO₂

COV Percentages:
- 0%
- 25%
- 50%
- 75%
- 100%

% COV

Aerosol Instruments

Between laboratories COV

- DDC surface
- CPC conc.
- ELPI conc.
- DGI total mass
- ELPI mean dp

COV Percentages:
- 0%
- 25%
- 50%
- 75%
- 100%

Round-Robin Tests Conducted Before the Main Measurement Campaign

Comparison of Results during the Main Measurement Campaign

Between laboratories COV

% COV

<table>
<thead>
<tr>
<th></th>
<th>50 km/h</th>
<th>Cold NEDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>NOx</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>HC</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>CO2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>DDC surface</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>CPC conc.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>ELPI conc.</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>DGI total mass</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>ELPI mean dp</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>SMPS conc.</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>SMPS mean dp</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
On-Road Chasing of Exhaust Plume

Test vehicle:
VW Golf TDI 1.9 l Euro 3
speed, fuel consumption
EN590 diesel (280 ppm S)

Ford Mobile Lab:
SMPS, CPC, NOx, CO₂
T and RH

Test track:
high speed oval, 4 km/lap
14 m distance: 0.4 s (120 km h⁻¹)
1 s (50 km h⁻¹)

Validation With Chasing Experiment

Vehicle: **Euro 3 VW Golf**, 
Chasing Experiment: DR 2500:1 @ 50 km/h, 7000:1@ 120 km/h, $T_{amb}=5^\circ C$, RH=50%
Lab Experiment: PDR: 12,5:1, TDR: ~1000:1, DAT: 32°C, Residence Time: 0.6-2.5 s

# Vehicle/engine characteristics

<table>
<thead>
<tr>
<th>Emission Standard</th>
<th>Make</th>
<th>Engine Size [l]</th>
<th>Power @ engine speed [kW/rpm]</th>
<th>After-Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light Duty Vehicles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 2</td>
<td>VW Golf TDI</td>
<td>1.9</td>
<td>66/4000</td>
<td>DOC</td>
</tr>
<tr>
<td>Euro 2</td>
<td>Peugeot 406 HDI</td>
<td>2.0</td>
<td>79/4000</td>
<td>DOC</td>
</tr>
<tr>
<td>Euro 3</td>
<td>Renault Laguna dCi</td>
<td>1.9</td>
<td>78/4000</td>
<td>DOC</td>
</tr>
<tr>
<td>Euro 3</td>
<td>VW Golf TDI (3 indiv. vehicles)</td>
<td>1.9</td>
<td>74/4000</td>
<td>DOC</td>
</tr>
<tr>
<td>Euro 3+</td>
<td>Peugeot 307 SW</td>
<td>2.0</td>
<td>79/4000</td>
<td>DOC+DPF</td>
</tr>
<tr>
<td>Euro 3+</td>
<td>Peugeot 607 HDI</td>
<td>2.2</td>
<td>98/4000</td>
<td>DOC+DPF</td>
</tr>
<tr>
<td><strong>Heavy Duty Engines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 1</td>
<td>Volvo</td>
<td>12.0</td>
<td>247/1900</td>
<td>w/o</td>
</tr>
<tr>
<td>Euro 2, Euro 3+</td>
<td>Volvo DH10A</td>
<td>9.6</td>
<td>210/2000</td>
<td>w/o, CRDPF</td>
</tr>
<tr>
<td>Euro 3, Euro 4</td>
<td>Scania DC11</td>
<td>10.6</td>
<td>250/1900</td>
<td>w/o, SCR</td>
</tr>
<tr>
<td>Euro 3, Euro 3+</td>
<td>Volvo D12C</td>
<td>12.1</td>
<td>247/1900</td>
<td>w/o, CRDPF</td>
</tr>
<tr>
<td>Euro 3</td>
<td>Scania DC12</td>
<td>11.7</td>
<td>300/1800</td>
<td>w/o</td>
</tr>
<tr>
<td>Euro 4</td>
<td>AVL Prototype</td>
<td>10.6</td>
<td>300/1900</td>
<td>CRDPF</td>
</tr>
<tr>
<td>Euro 5</td>
<td>AVL Prototype</td>
<td>11.7</td>
<td>300/1800</td>
<td>SCR</td>
</tr>
<tr>
<td><strong>Medium/Heavy Duty Vehicles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 3</td>
<td>IVECO Eurocargo</td>
<td>3.9</td>
<td>125/2700</td>
<td>w/o</td>
</tr>
<tr>
<td>Euro 3</td>
<td>Mercedes Citaro</td>
<td>12.0</td>
<td>185/2000</td>
<td>w/o, PM Cat</td>
</tr>
</tbody>
</table>
Experimental: Gasoline Vehicle Sample

- **Port injection SI (G)**
  - four Euro 3
  - one Euro 1
  - one Californian ULEV

- **Direct injection SI (DISI)**
  - two stoich. with TWCs
  - three lean with NOx adsorber and TWC

All well maintained and <50 000 km mileage.
Only ULEV and Euro 1 gasoline cars had > 100 000 km.
Experimental: Fuel Matrix

<table>
<thead>
<tr>
<th>Fuel Code</th>
<th>Sulphur mg/kg</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>1550</td>
<td>Historic diesel</td>
</tr>
<tr>
<td>D2</td>
<td>280</td>
<td>2000 diesel</td>
</tr>
<tr>
<td>D3</td>
<td>38</td>
<td>2005 diesel</td>
</tr>
<tr>
<td>D4</td>
<td>8</td>
<td>2009 diesel</td>
</tr>
<tr>
<td>D5</td>
<td>3</td>
<td>Swedish Class 1</td>
</tr>
<tr>
<td>D6</td>
<td>307</td>
<td>pre 2000 fuel</td>
</tr>
<tr>
<td>D7</td>
<td>7</td>
<td>D4 + 5% RME</td>
</tr>
<tr>
<td>G1</td>
<td>143</td>
<td>2000 gasoline</td>
</tr>
<tr>
<td>G2</td>
<td>45</td>
<td>2005 gasoline</td>
</tr>
<tr>
<td>G3</td>
<td>6</td>
<td>2009 gasoline</td>
</tr>
</tbody>
</table>

Only tested on some engines/vehicles
Based on the EU *Particulates* Research project activities, results and database (http://lat.eng.auth.gr/particulates/)

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- **Results from Light Duty Vehicles** and HDVs
- Comparison of Diesel particle exhaust emissions from Light Duty vehicles and Heavy Duty engines
- Diesel Particulate Filter Efficiency
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LDV Test Cycles: Regulatory NEDC and Real World Driving Cycles
(Common Artemis Driving Cycles = CADC)
LDV Results: Regulated PM

NEDC

Motorway

Regulated PM [g · km⁻¹]

Diesel Euro 3
Diesel Euro 2
Diesel Euro 1
Diesel +DPF
DISI lean
DISI stoich.
Gas. Euro 1
Gas. Euro 3
Gas. ULEV

LDV Results: Solid Particle Number (TD+ELPI)

Solid particle emission rate [km⁻¹]

NEDC

Motorway

Diesel Euro 3  
Diesel Euro 2  
Diesel Euro 1  
Diesel +DPF  
DISI lean  
DISI stoich.  
Gas. Euro 3  
Gas. Euro 1  
Gas. ULEV

Results: Active Surface (Diff. Charger)

Cold NEDC

Motorway

LDV Results: Total Particle Number (CPC)

LDV Results: Total Particle Size Distribution (SMPS) - Diesel

LDV Results: Total Particle Size Distribution (SMPS) - Gasoline

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HDV Results: Regulated PM

- Very low PM emissions achieved with CRT equipped systems on low sulphur fuels, & with Euro-V SCR/urea prototype without DPF
- Benefits of fuel sulphur reduction also evident
Conventional Euro-I to Euro-III engine technologies produced total solid particle number emissions in the range of $10^{14}$ particles/kWh.

- Results for one Euro-III engine are an order of magnitude lower, needing further explanation.
- DPF systems offer the potential to reduce solid particle numbers by 3-4 orders of magnitude.
- Euro-V system with SCR/urea (without DPF) produced around $10^{13}$ particles/kWh, ca. 90% < typical Euro-III cases, but 2 orders of magnitude higher than best DPF systems.
Euro-I to Euro-III engines produced active surface values in the range $10^5$ to $10^6$ cm²/kWh. The Euro-III engine with CRT gave 1-2 orders of magnitude reduction, broadly in-line with its ELPI performance.

The Euro-II engine with CRT gave active surface values in the same range as the Euro-I to Euro-III conventional engines, indicating formation of high number of nucleation mode particles.
Total particle number (CPC) emissions of conventional Euro-I to Euro-III heavy duty diesel engines were in the range $10^{14}$ to $10^{16}$ particles/kWh.

DPF systems operating on low sulphur fuels have the capability to reduce the total number count by ca. 3 orders of magnitude. However, some cases showed high numbers of nucleation mode particles, particularly at high temperatures.

Sulphur effects also evident.
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Comparison of Diesel particle exhaust emissions from Light Duty vehicles and Heavy Duty engines

- Due to the different regulatory steps and definitions, there is no clear view on how diesel LD vehicle emissions compare to HD and results on diesel emissions that appear in the literature may contradict.

- Target is to present particle emission rates and size distributions from HD and LD vehicles, expressed on a per distance traveled and on a per unit of fuel consumed basis to enable a straightforward comparison.

- This information can be used to estimate the contribution of trucks, busses and cars to ambient concentrations and to understand differences in their emission behavior.
Driving Cycles / Operation modes

Urban

Heavy-Duty

Light-Duty

SAE Transactions Paper 2006-01-0866
Calculation steps for distance specific emissions of HDVs

(1) Work specific solid particle number emissions for HDEs

(2) Mean positive cycle work per kilometer driven

Example for average-sized 2-axle coaches (50% loaded, 0% road gradient) in real world driving cycles

Calculated by the model PHEM

SAE Transactions Paper 2006-01-0866
### Typical particle emission values and ranges for different vehicle categories in urban and highway driving, using low sulfur fuel (<10 ppm wt.)

<table>
<thead>
<tr>
<th>Category</th>
<th>Emission Standard</th>
<th>PM [g/km]</th>
<th>(N_{sol} \times 10^{14} ) [#/km]</th>
<th>Act. Surf. [m²/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urban Driving</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>Euro 3</td>
<td>0.06</td>
<td>1.8</td>
<td>10-15</td>
</tr>
<tr>
<td>Pass Car + DPF</td>
<td>Euro 3+</td>
<td>0.002</td>
<td>(&lt;2 \times 10^{11})</td>
<td>(&lt;0.0024)</td>
</tr>
<tr>
<td>Urban Bus</td>
<td>Euro 3</td>
<td>0.20</td>
<td>5.2</td>
<td>28-88</td>
</tr>
<tr>
<td>Truck (7.5 tn)</td>
<td>Euro 3</td>
<td>0.15</td>
<td>3.4</td>
<td>18-58</td>
</tr>
<tr>
<td>Truck (16 tn)</td>
<td>Euro 3</td>
<td>0.33</td>
<td>8.7</td>
<td>47-146</td>
</tr>
<tr>
<td>Truck (16 tn) + CRDPF</td>
<td>Euro 4</td>
<td>0.06</td>
<td>(~10^{11})</td>
<td>n.a.</td>
</tr>
<tr>
<td>Truck (16 tn) + SCR</td>
<td>Euro 5</td>
<td>0.06</td>
<td>0.48</td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>Highway Driving</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>Euro 3</td>
<td>0.04</td>
<td>1.9</td>
<td>12-15</td>
</tr>
<tr>
<td>Passenger Car + DPF</td>
<td>Euro 3+</td>
<td>0.002</td>
<td>(&lt;2 \times 10^{11})</td>
<td>(&lt;0.0036)</td>
</tr>
<tr>
<td>Coach</td>
<td>Euro 3</td>
<td>0.11</td>
<td>2.0</td>
<td>11-26</td>
</tr>
<tr>
<td>Truck (7.5 tn)</td>
<td>Euro 3</td>
<td>0.08</td>
<td>1.4</td>
<td>8-19</td>
</tr>
<tr>
<td>Truck (16 tn)</td>
<td>Euro 3</td>
<td>0.18</td>
<td>2.4</td>
<td>14-32</td>
</tr>
<tr>
<td>Truck (16 tn) + CRDPF</td>
<td>Euro 4</td>
<td>0.02</td>
<td>(~10^{11})</td>
<td>n.a.</td>
</tr>
<tr>
<td>Truck (16 tn) + SCR</td>
<td>Euro 5</td>
<td>0.02</td>
<td>0.03</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

**Emissions proportional to engine size**

**No visible association with engine size**

SAE Transactions Paper 2006-01-0866
Results: Emissions per unit fuel consumed - PM

- Cars tuned towards low NOx / high PM emissions
- HDVs tuned towards high NOx, high efficiency

<table>
<thead>
<tr>
<th>Euro Level</th>
<th>NOx [g/kWh]</th>
<th>PM [g/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LDV</td>
<td>HDE</td>
</tr>
<tr>
<td>Euro 2</td>
<td>4.1</td>
<td>7.0</td>
</tr>
<tr>
<td>Euro 3</td>
<td>3.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Euro 4</td>
<td>1.7</td>
<td>3.5</td>
</tr>
<tr>
<td>Euro 5</td>
<td>1.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>

SAE Transactions Paper 2006-01-0866
Results: Emissions per unit fuel consumed
Particle Number

Solid

Total

Nucleation mode is associated with the low solid particle number emissions of HDVs.
Particle size distributions from LDVs, HDEs and HDVs

HDE tend to produce nucleation particles at low loads probably due to high SOF

LDV tend to produce nucleation particles at high loads probably due to sulphates
Results: Effect of aftertreatment - HD

- **OEM DPF reduces solid particle number by more than 3 orders of magnitude**
- **Engine tuning for SCR application reduces particle number by 1 order of magnitude and leads to highest NOx reductions**
- **DPF retrofitting has a positive but variable effect. All reductions beyond one order of magnitude**
- **The PM catalyst has a negligible overall effect**
Results: Effect of aftertreatment - HD

- Results are more difficult to interpret due to the NM formation
- SCR reduces particle number without inducing NM formation
Results: Effect of aftertreatment - LD

Solid particle number emission rate \([\text{g}_{\text{fuel}}^{-1}]\)

- Both retrofitted and OEM DPF seem to reduce solid particle number by at least 3 orders of (ELPI limit of detection)
Particle reduction by OEM DPF may reach up to 6 orders of magnitude.

Total particle number may reach conventional levels during regeneration.

There is room for more rigorous control of condensable species in the exhaust gas.
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Diesel Particle Filters – Test Vehicle - Fuels

- Ce-based additive (CeDPF) at 25 ppm
  - NGK SiC $\varnothing 144$ mm×L 152.4 mm (5.66"×6"),
  - cell density of 200 cpsi and wall thickness of 0.38 mm.
- Catalyzed soot filter (CSF) with Pt-based catalyst
  - NGK SiC $\varnothing 144$ mm×L 152.4 mm (5.66"×6"),
  - cell density of 300 cpsi and a wall thickness of 0.30 mm
  - material porosity and mean pore size were also larger than the CeDPF (before the washcoat application).

- Test Vehicle
  - 2001 model year Renault Laguna 1.9 dCi meeting Euro 3 emission standards
- Two fuels complying with EN590 specifications were used
  - A higher sulphur fuel (HSF) 38 ppm wt.
  - A lower sulphur fuel (LSF) 8 ppm wt.
- Lubrication oil
  - 15W-40 grade (ACEA A3/B3) with $\sim$6000 ppm wt. sulphur

Particle mass (PM) and particle properties for the fuel and vehicle configurations studied (1/2)

Error bars correspond to min-max of two measurements conducted at different days.

Particle mass (PM) and different airborne particle properties for the fuel and vehicle configurations studied (2/2)

Error bars correspond to min-max of two measurements conducted at different days.

Effect of CSF soot loading level on particle size distributions
120 km/h

H, L correspond to "higher" and "lower" loadings respectively.

Filtration efficiency (expressed in %) of DPFs, based on different particle properties

<table>
<thead>
<tr>
<th>Measure</th>
<th>Driving Cycle</th>
<th>CSF 38 ppm S</th>
<th>CSF 8 ppm S</th>
<th>CeDPF 8 ppm S</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>NEDC</td>
<td>96.94</td>
<td>98.12</td>
<td>98.39</td>
</tr>
<tr>
<td></td>
<td>Artemis</td>
<td>97.44</td>
<td>95.30</td>
<td>98.59</td>
</tr>
<tr>
<td>Active Surface (DC)</td>
<td>NEDC</td>
<td>99.96</td>
<td>99.93</td>
<td>99.95</td>
</tr>
<tr>
<td></td>
<td>Artemis</td>
<td>99.71</td>
<td>99.88</td>
<td>99.95</td>
</tr>
<tr>
<td>Solids Number (ELPI)</td>
<td>NEDC</td>
<td>99.94</td>
<td>99.93</td>
<td>99.96</td>
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<tr>
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<td>Artemis</td>
<td>99.93</td>
<td>99.91</td>
<td>99.98</td>
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<tr>
<td>Total Number (CPC)</td>
<td>NEDC</td>
<td>99.92</td>
<td>99.89</td>
<td>99.87</td>
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<tr>
<td></td>
<td>Artemis</td>
<td>99.95</td>
<td>99.88</td>
<td>99.94</td>
</tr>
<tr>
<td>Total Number (SMPS)</td>
<td>50 km/h</td>
<td>99.94</td>
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<td>99.87</td>
</tr>
<tr>
<td></td>
<td>90 km/h</td>
<td>99.94</td>
<td>99.96</td>
<td>99.92</td>
</tr>
<tr>
<td></td>
<td>120 km/h</td>
<td>35.67</td>
<td>99.96</td>
<td>99.94</td>
</tr>
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</table>

Due to nucleation

Semi-volatile (or Nucleation Mode – NM) nanoparticles can be measured in a reliable and repeatable manner, at both LDVs and HDVs.

**Nucleation mode formation in HDVs:**
- Frequent due to low specific solid particle number
- More prominent at low loads (higher SOF emissions)
- Decreases at high loads
- Decreases with oxidation catalysts

**Nucleation mode formation in LDVs:**
- Not present at low loads due to efficient oxidation catalysts
- Possibility to form at high load, due to sulfate formation, even with sub 10 ppm S fuel and medium S lube oil
**Aftertreatment systems:**

- DPFs are most effective for solid particle number (reductions up to 6 orders of magnitude). NM particles may form in some configurations.

- SCR+advanced engine tuning leads to one order of magnitude less solid particle numbers with no NM formation appearing (+NOx reduction)

- A “PM-Catalyst” reduced NM particles more effectively than a DOC but had little effect on solid particle number over transient tests.

Further research continues to be needed on the health relevance of measurements of “nucleation” mode particles, their chemical composition and their fate in the atmosphere.
Proposal for a European Centre of Expertise on Road Transport Related PM (ECERT-PM)

Co-Ordination
(Chair, Steering Body, other)

WG Emissions

WG Toxicology

Link to EC, WHO, EEA, CLRTAP, ...

WG Hot-Spots

WG Standards
Thank you for your attention