Title: Reduction of exhaust nanoparticles by retrofitted after-treatment systems in diesel passenger cars

Abstract: (min. 300 - max 500 words)

Vehicle exhaust emissions constitute an environmental and health hazard. Recent investigations on climate change have made apparent that traffic-based CO₂ emissions should be restrained. Since diesel vehicles emit less CO₂ than gasoline vehicles, we can expect that the number of diesel vehicles will increase. Consequently, particle emissions will enhance due to higher soot mode compared to gasoline vehicles. Before the more strict Euro standards force car manufacturers to equip all diesel vehicles with particle filters, nanoparticle reduction could be accomplished by retrofitted after-treatment systems, especially if the car fleet renewal is very slow as in Finland (18.3 years).

A retrofitted after-treatment system (oxidizing catalyst and diesel particle filter DPF by Twintec) were installed into two test diesel passenger cars (BMW 530d year 2002, VW Passat 2.0 TDI year 2007). The nanoparticle emissions were studied in the real-world conditions. The vehicles were chased by a mobile laboratory van Sniffer (Pirjola et al., 2004a; Pirjola et al., 2004b) with a distance of 4 m. The measurements were performed with high and low engine loads. The driving speed was constant 40 km h⁻¹. To control the activity of the DPF the temperature and pressure sensors were installed before and after the after-treatment system.

Particle size distributions were measured by the electrical low pressure impactor (ELPI, Dekati Inc.) and two scanning mobility particle sizers (SMPS); one equipped with DMA 3085 and CPC 3025 (Nano-SMPS, TSI Inc.) and the other with DMA 3071 and CPC 3775 (SMPS, TSI Inc.) nearly similar as in Rönkkö et al. (2007). Particle volatility was studied by using a thermodenuder. Also recorded were the gaseous species such as CO, CO₂, NO, NO₂, and NOₓ as well as the driving parameters and fuel consumption. To determine the dilution ratio, the raw exhaust CO₂ concentrations with the same engine loads were measured on the chassis dynamometer by Helsinki Polytechnic.

The particle number and volume size distributions in the raw exhaust were derived based on the measurements with and without the filter. A clear reduction was seen indicating the benefit of the filter. For the older car BMW,
the total number concentration decreased by ~63% for high load and ~42% for low load whereas for Passat the values were 26% and 9 %, respectively (Figure 1). By using the filter, the CO$_2$ emissions were not significantly enhanced. Effects of exhaust temperature on particle properties will be discussed.

![Bar chart showing reduction percent of soot particles due to the retrofitted after-treatment systems.](image)

Figure 1. Reduction percent of soot particles due to the retrofitted after-treatment systems.


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**Short CV: Liisa Pirjola**

- degree of Ph. D. at University of Helsinki, Dept. of Physics, in 1998
- Docent (Adj. Prof.) at University of Helsinki since 2000
- principal lecturer at Helsinki Polytechnic, Dept. of Technology, since 2001
- more than 60 peer reviewed papers
- research interests include aerosol dynamic modelling, atmospheric particles, atmospheric chemistry, traffic pollution, exhaust and non-exhaust particles, mobile laboratory measurements

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Reduction of exhaust nanoparticles by retrofitted after-treatment systems in diesel passenger cars

Liisa Pirjola¹,², Topi Rönkkö³, Heikki Parviainen¹, Annele Virtanen³ and Jorma Keskinen³

¹Department of Technology, Helsinki Polytechnic (Stadia), P.O. Box 4020, FIN-00099 Helsinki, Finland
²Department of Physics, University of Helsinki, P.O. Box 64, FIN-00014 Helsinki, Finland
³Department of Physics, Tampere University of Technology, P.O. Box 692, FIN-33101 Tampere, Finland
Background for this work

Traffic exhaust emissions

Particles, NOx, PAH

- Adverse health effects
- Soot particles increase

Retrofitted filters

- EU standards

- Greenhouse gases CO₂, N₂O soot particles

- EU biofuel directive

- To restrain CO₂ emissions

Climate change

- Finnish tax policy for new cars

- Increase in diesel vehicles

Passenger cars: diesel ~13% New diesels this year ~50%
Experimental method

• a retrofitted after-treatment system (oxidizing catalyst and particle filter) were installed into two test diesel passenger cars
  - EURO 3: BMW 530d, year 2002
  - EURO 4: VW Passat 2.0 TDI, year 2007

• on road chasing experiments were performed by a mobile laboratory Sniffer in Alastaro, Finland

• chasing distance 4 m

• driving speed 40 km/h

• high load and low load driving conditions one after the other several times

• driving parameters recorded with the KTS vehicle diagnostic system
Driving conditions

- constant driving conditions

<table>
<thead>
<tr>
<th></th>
<th>Low engine load</th>
<th>High engine load</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Boost pressure (kPa)</td>
<td>Wheel power (kW)</td>
</tr>
<tr>
<td>VW Passat with filter</td>
<td>125</td>
<td>5.5</td>
</tr>
<tr>
<td>VW Passat without filter</td>
<td>126</td>
<td>5.6</td>
</tr>
<tr>
<td>BMW with filter</td>
<td>110</td>
<td>6.7</td>
</tr>
<tr>
<td>BMW without filter</td>
<td>110</td>
<td>6.9</td>
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</tbody>
</table>
Twintec PM-filter catalyst (PFC)

- open system with passive regeneration
- NO oxidizes to NO₂ on catalytic coated surfaces on a catalyst
  \[ NO + \frac{1}{2}O_2 \leftrightarrow NO_2 \]
- NO₂ reacts with soot particles at appr. 200°C
  \[ 2NO_2 + C \rightarrow CO_2 + 2NO \]
- continuous regeneration, no danger of clogging up
- low back pressure, no reduction of fuel mileage
- a part of flow passes directly through the fleece to the neighbouring channel
- much larger part flows through the fleece in the direction of flow or along the surface of the fleece
- particles are collected on the fleece surface mainly by diffusion
- only as many particles are tracked as can be regenerated via NO2 (controlled by the metal PM-Metalit® by Emitec)
- 30-50% (even 70%) PM reduction rates
Instrumentation

- mobile laboratory Sniffer: a Diesel vehicle, Volkswagen LT35 designed and built by Stadia (Pirjola et al. 2004; 2006).
- sampling above the front bumpers
- ELPI (Electrical Low Pressure Impactor), aerodynamic diameter 7 nm - 6.6 μm, 12 stages, 1s
- NanoSMPS (DMA 3085+CPC 3025), mobility diameter 3 - 60 nm, 90 s
- SMPS (DMA 3071+CPC 3025), 10-400 nm, 90 s
- thermodenuder
- Gas analysers: CO, CO2, NO, NO2
- Weather station at 2.9 m altitude, gps
- temperature and pressure sensors before and after the filter system
Dilution ratio

• On road measurements for CO₂
• additionally chassis dynamoeter measurements performed in the emission laboratory of Helsinki Polytechnic with the same engine loads
• dilution ratios as a function of time as well as the averages calculated
• (* refers to denuder, green to filter, yellow to without filter)
Results (no PFC, high vs. low load)

- thermodenuder 260 °C => non-volatile soot mode
- GMD larger for higher engine load
- number concentration 29% (BMW) and 22% (VW) larger for high load than for low load
- volume concentration 3-fold (BMW) and 2-fold (VW) compared with low load
Results (PFC, number size distribution)
Results (reduction percents)

Particle number reduction

- BMW 530d
- VW Passat

Particle volume reduction

- BMW 530d
- VW Passat
Results \((PFC,\ denuder,\ BMW)\)
Results (PFC, no denuder, BMW)

Rönkkö et al., 2008 submitted to EST
Results (PFC, denuder, VW Passat)
Results
Conclusions

- exhaust emissions: simultaneous reduction of CO$_2$, NO$_x$ and PM are needed

- the mobile chasing measurements under real driving conditions show that retrofitted filters decreased exhaust particle number concentrations (40-60%) and mass concentrations (20-60%)

- however, reduction depends on driving conditions, oxidizing catalysts and vehicles

- more measurements are needed (several vehicles, different driving conditions, different after-treatment systems)

- long-time measurements are needed to follow filter’s efficiency, also under winter conditions

- dynamometer tests

- effects on nucleation mode particles
Acknowledgements

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