12th ETH-Conference on Combustion Generated Nanoparticles
June 23rd – 25th 2008

Paper-Abstract Form

Name of Author: Liisa Pirjola[1,2]
Co-Authors: Topi Rönkkö[3], Heikki Parviainen[1], Annele Virtanen[3], Jorma Keskinen[3]
Affiliation: [1]Department of Technology, Helsinki Polytechnic, Finland
[2]Department of Physics, University of Helsinki, Finland
[3]Department of Physics, Tampere University of Technology, Finland

Mailing address: [1]P.O. Box 4020, FIN-00099 Helsinki, Finland
[2]P.O. Box 64, FIN-00014 Helsinki, Finland
[3]P.O .Box 692, FIN-33101, Tampere, Finland
Phone / Fax : +358-9-31083245/ +358-9-31083350
E-mail : liisa.pirjola@stadia.fi, liisa.pirjola@helsinki.fi

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

Abstract: (min. 300 - max 500 words)

The abstracts for papers and posters should contain unpublished information on the research subject, the investigation methods and results obtained so far. Graphs and references are very welcome. During your presentation at the conference you may expand on this with additional data and results. General information on products which are already commercially available are not the focus of the presentations but are very welcome at the exhibition.

Vehicle exhaust emissions constitute an environmental and health hazard Recent investigations on climate change have made apparent that traffic based CO_2 emissions should be restrained. Since diesel vehicles emit less CO_2 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 renews very slowly 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, CO_2, NO, NO_2, and NO_x as well as the driving parameters and fuel consumption. To determine the dilution ratio, the raw exhaust CO_2 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.

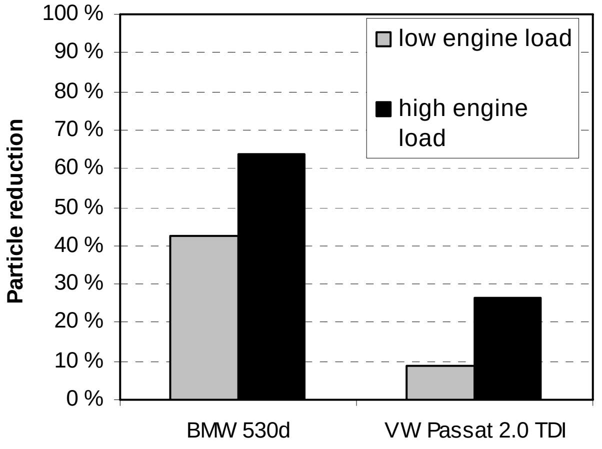


Figure 1. Reduction percent of soot particles due to the retrofitted after-treatment systems.

Pirjola, L., Parviainen, H., Hussein, T., Valli, A., Hämeri, K., Aalto, P., Virtanen, A., Keskinen, J., Pakkanen, T., Mäkelä, T., Hillamo, R. (2004a). Atmospheric Environment 38, 3625-3635.

Pirjola, L., Parviainen, H., Lappi, M., Hämeri, K. and Hussein, T. (2004b). SAE-paper no 2004-01-1962.

Rönkkö, T., Virtanen, A., Kannosto, J., Keskinen, J., Lappi, M., and Pirjola, L. (2007). Environmental Science and Technology, 41, 6384-6389.

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

Return by Email latest 28th of March 2008 to ttm.a.mayer@bluewin.ch

12th ETH-Conference on Combustion Generated Nanoparticles
June 23rd –25th 2008, ETH Zentrum, Zûrich

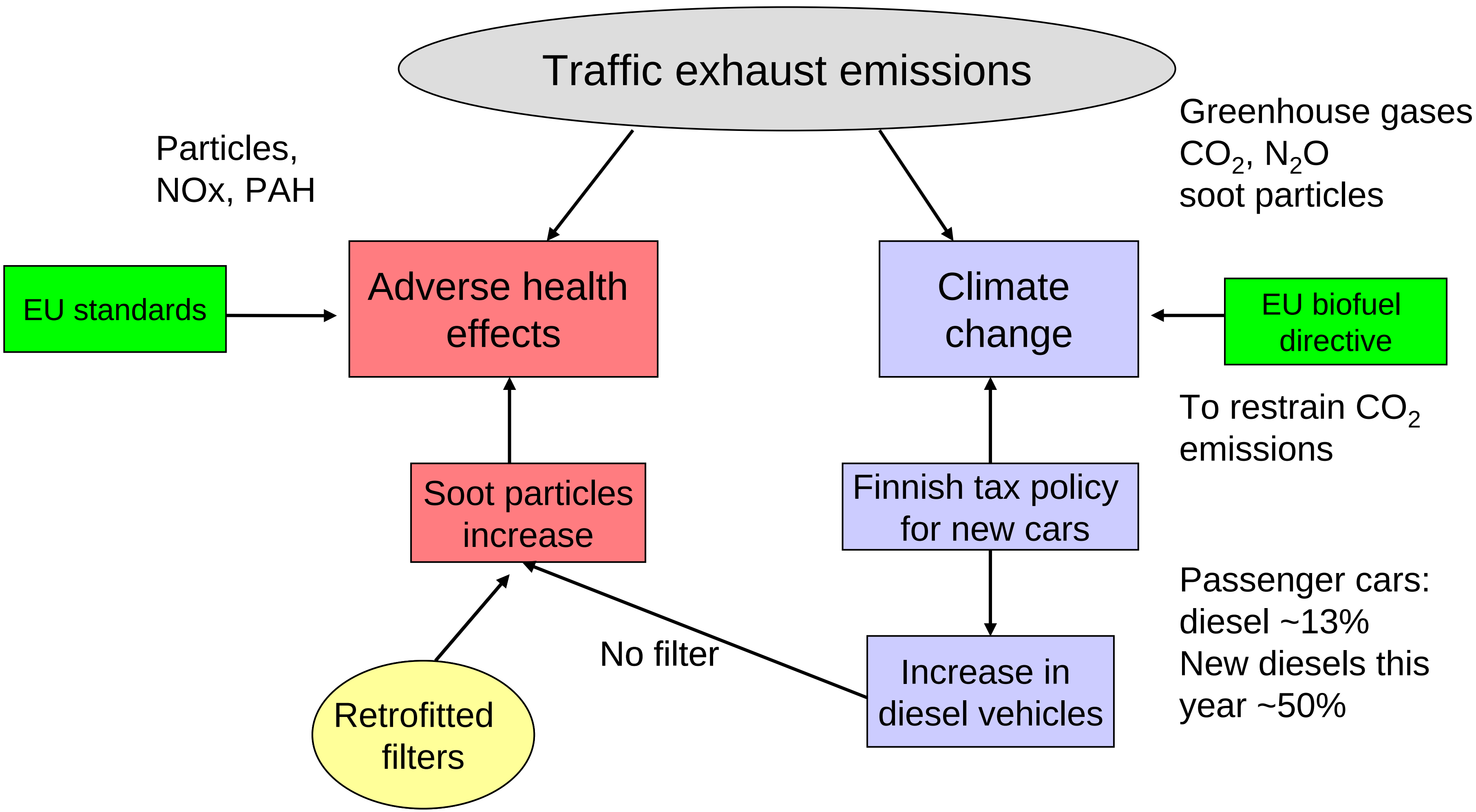
Reduction of exhaust nanoparticles by retrofitted after-treatment systems in diesel passenger cars

Liisa Pirjola[1,2], Topi Rönkkö[3], Heikki Parviainen[1], Annele Virtanen[3] and Jorma Keskinen[3]

[1]Department of Technology, Helsinki Polytechnic (Stadia), P.O. Box 4020, FIN-00099 Helsinki, Finland
[2]Department of Physics, University of Helsinki, P.O. Box 64, FIN-00014 Helsinki, Finland
[3]Department of Physics, Tampere University of Technology, P.O .Box 692,

FIN-33101 Tampere, Finland

Background for this work



Experimental method

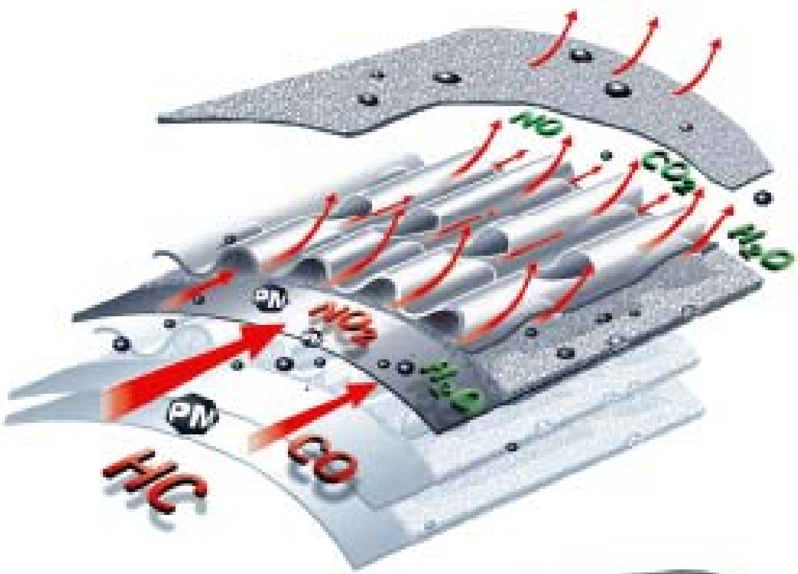
- a retrofitted after-treatment system (oxidizing catalyst and particle filter) were installed into two test diesel passenger cars
  - EURO 3: BMW 530d, year 2002
  - EURO 4: VW Passat 2.0 TDI, year 2007
- on road chasing experiments were performed by a mobile laboratory Sniffer in Alastaro, Finland
- 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

	Low engine load		High engine load	
	Boost pressure (kPa)	Wheel power (kW)	Boost pressure (kPa)	Wheel power (kW)
VW Passat with filter	125	5.5	168	21.6
VW Passat without filter	126	5.6	169	21.7
BMW with filter	110	6.7	160	32.7
BMW without filter	110	6.9	160	30.8

Twintec PM-filter catalyst (PFC)



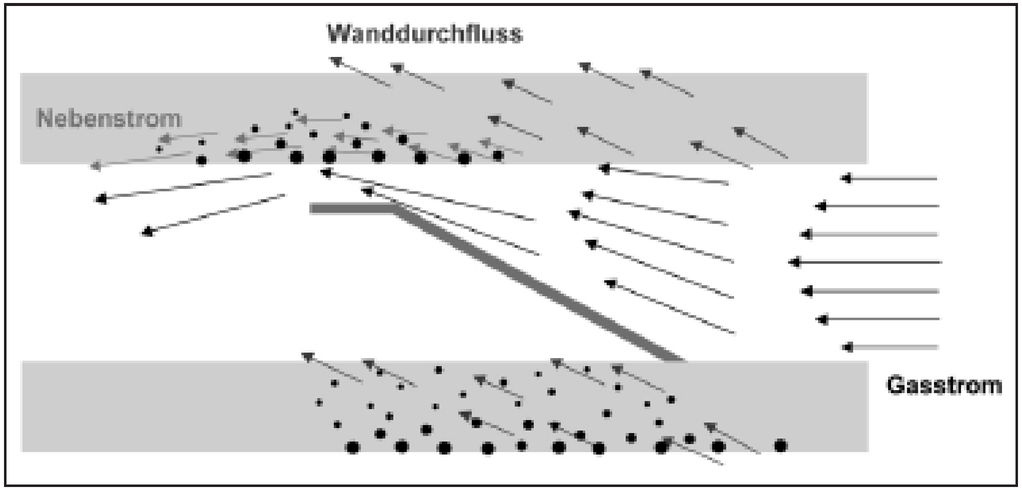
- open system with passive regeneration
- NO oxidizes to NO_2 on catalytic coated surfaces on a catalyst

$$NO + \frac{1}{2}O_2 \Leftrightarrow NO_2$$

- NO_2 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

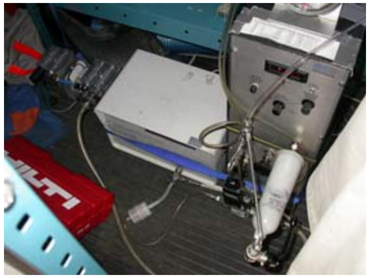


- a part of flow passes directly through the fleece to the neighbouring channel
- much larger part flows through the fleece in the direction of flow or along the surface of the fleece
- particles are collected on the fleece surface mainly by diffusion
- only as many particles are tracked as can be regenerated 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

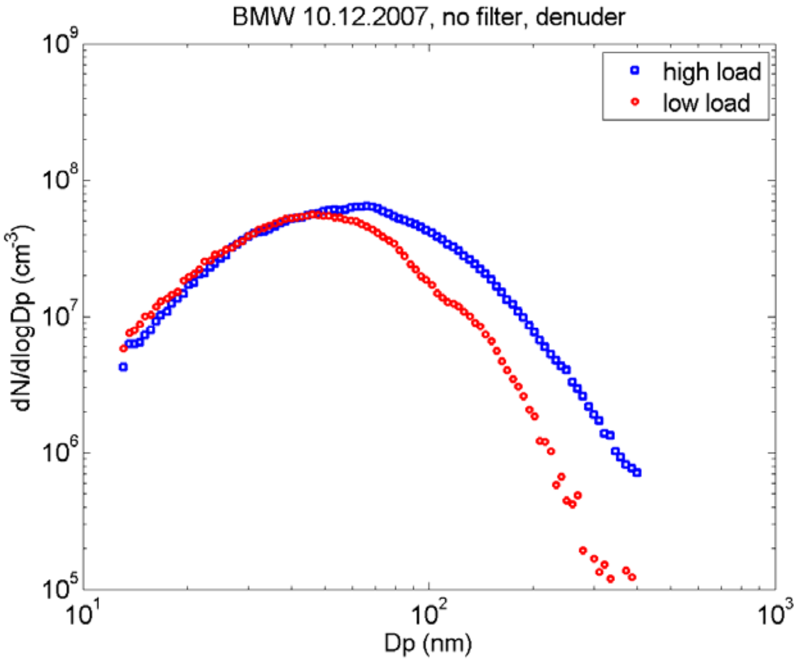
Dilution ratio

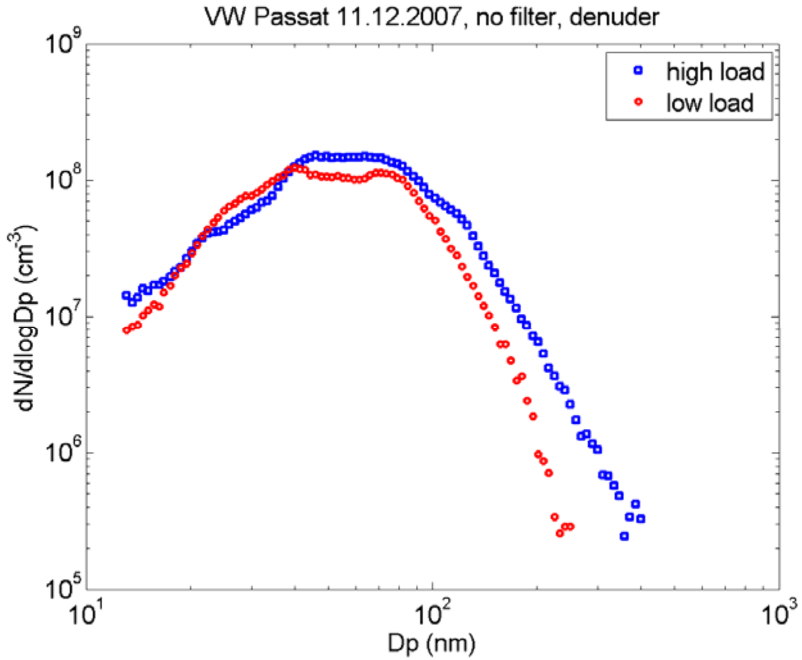
- On road measurements for CO_2
- additionally chassis dynamoter measurements performed in the emission laboratory of Helsinki Polytechnic with the same engine loads
- dilution ratios as a function of time as well as the averages calculated
- (* refers to denuder, green to filter, yellow to without filter)

VW Passat	DR-ave
load1	368.14
load2	310.98
load3	753.07
load4	661.86
load5	571.61
load6	586.06
Load7	595.35
load 8 *	760.12
noload1	491.89
noload2	368.27
noload3	791.79
noload4	715.83
noload5	933.53
noload6	749.37
Noload7 *	870.09
Noload8 *	789.88
load9	973.52
load10	658.60
load11	572.33
Load12 *	740.26
Load13 *	751.02
Load14 *	657.85
noload9	1144.36
noload10	1082.50
noload11	886.86
Noload12 *	935.60
Noload13 *	1117.71
Noload14 *	641.16

BMW 530d	DR-ave
load1	140.74
load2	150.26
load3	179.35
load4	198.69
load5	354.80
load6	404.83
Load7 *	197.50
noload1	278.66
noload2	328.30
noload3	296.64
noload4	285.73
noload5	271.37
noload6	526.67
Noload7 *	514.63
load8	251.17
load9	355.13
load10	266.94
Load10b *	201.56
Load11 *	607.76
load12 ·	295.89
load13	208.36
Load14 *	262.86
Load15 *	240.44
noload9	876.57
noload10	843.45
noload11	526.07
noload12	497.97
Noload13 *	420.89
noload14	443.84
noload15	389.67
Noload16 *	383.09
Noload17	526.57

Results (no PFC, high vs. low load)

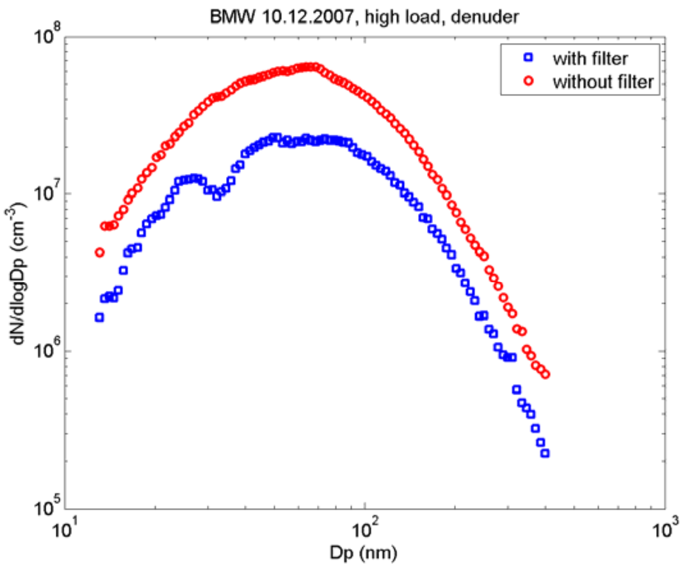




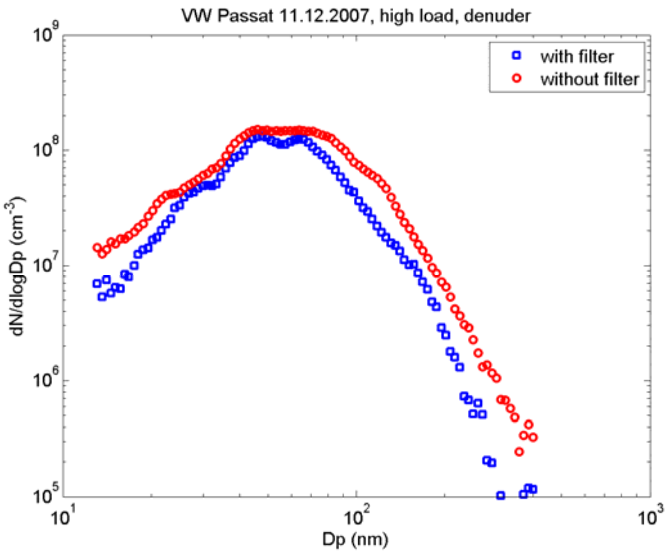
- thermodenuder 260 °C => non-volatile soot mode
- GMD larger for higher engine load
- number concentration 29% (BMW) and 22% (VW) larger for high load than for low load
- volume concentration 3-fold (BMW) and 2-fold (VW) compared with low load

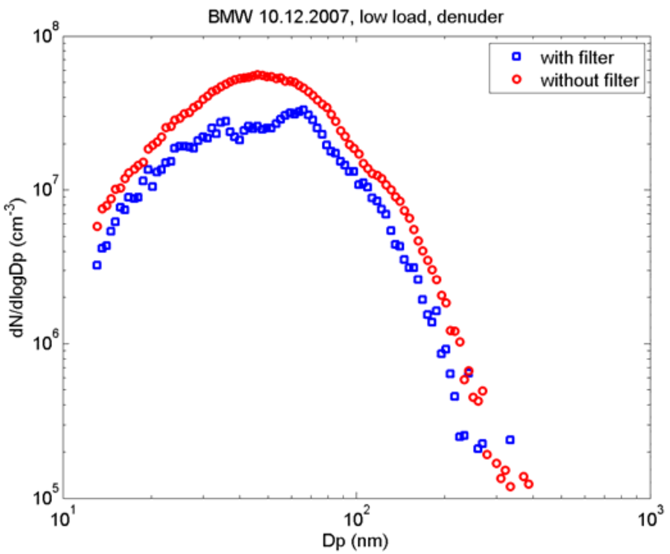
Results (PFC, number size distribution)

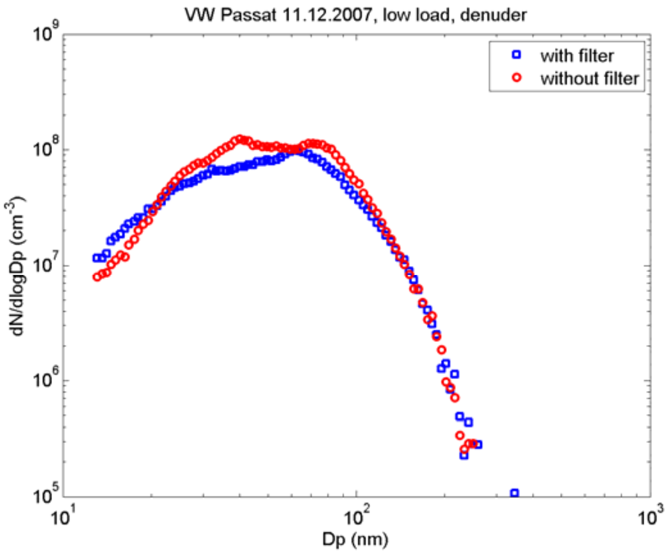
BMW



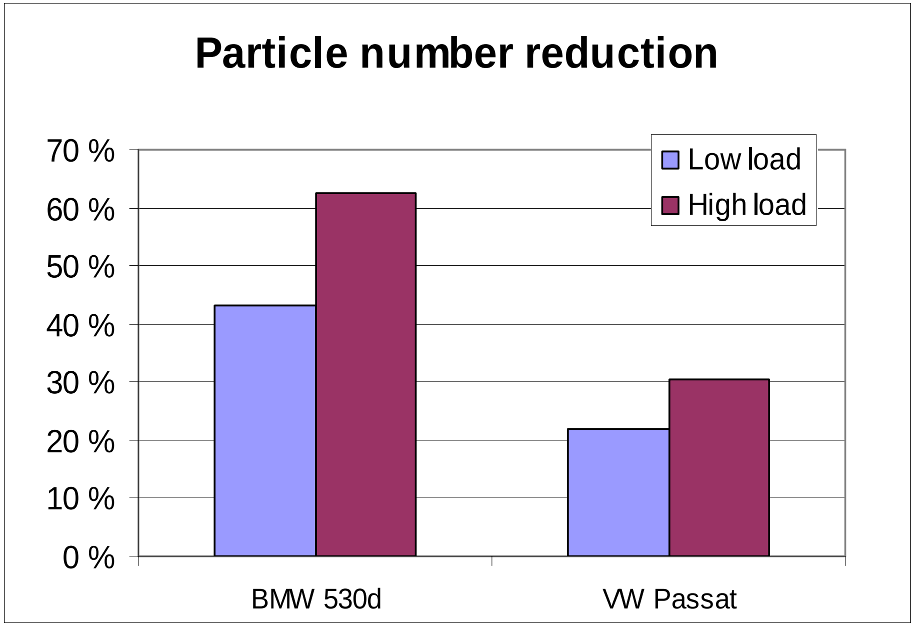
VW

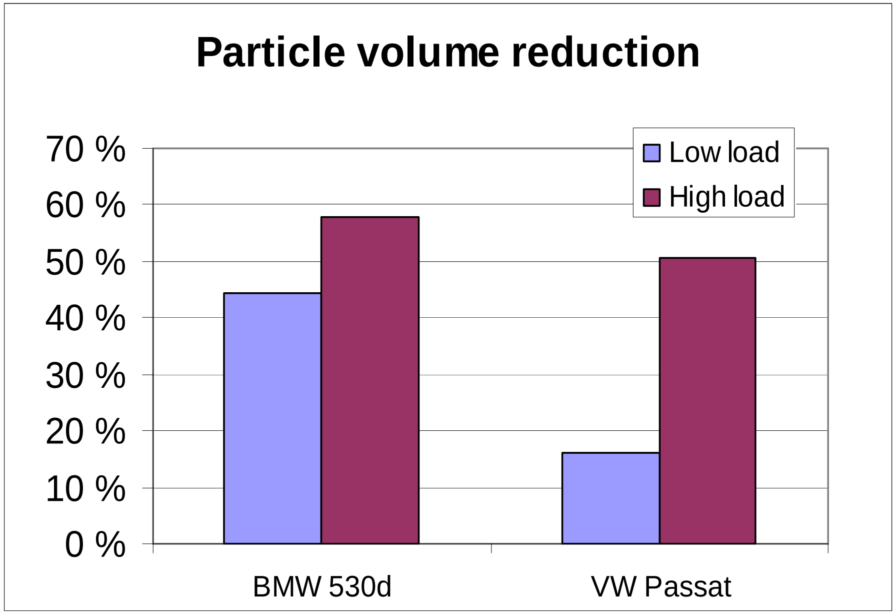




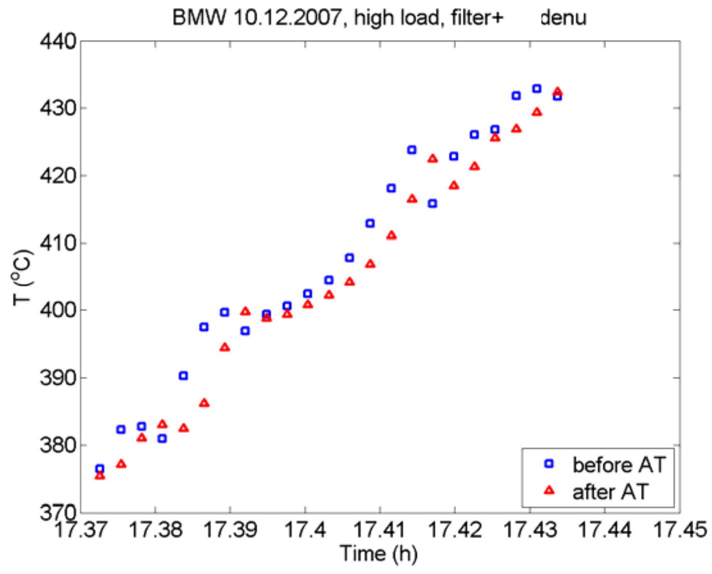


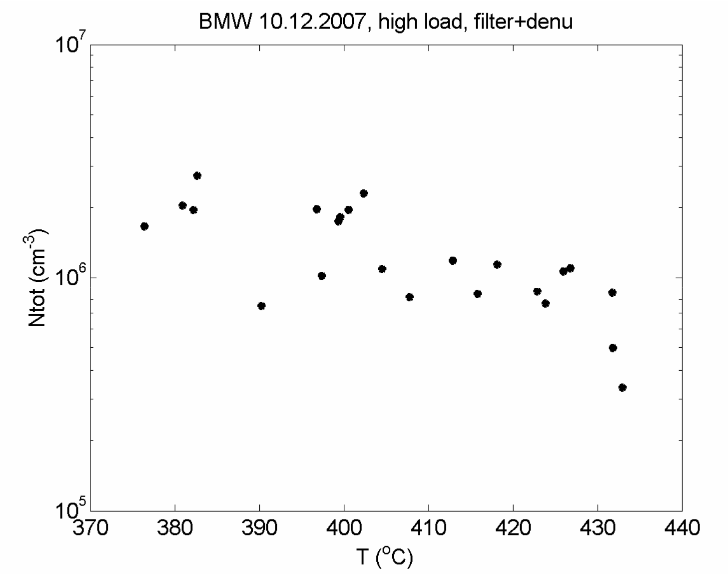
Results (reduction percents)

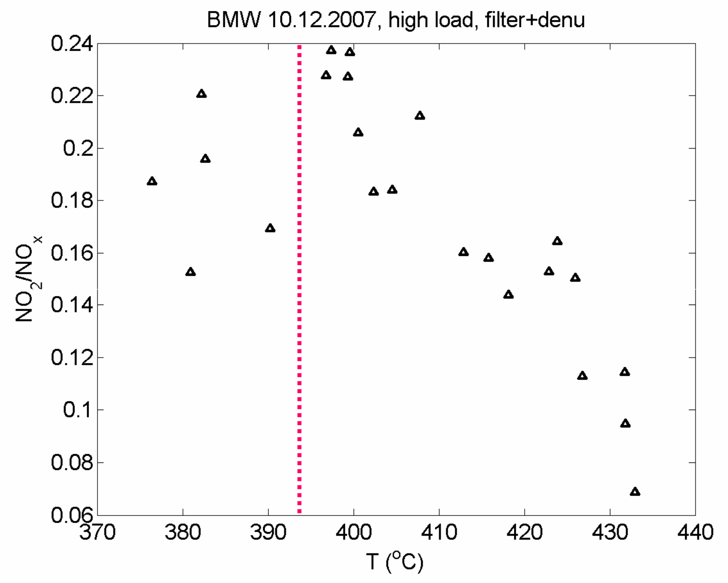




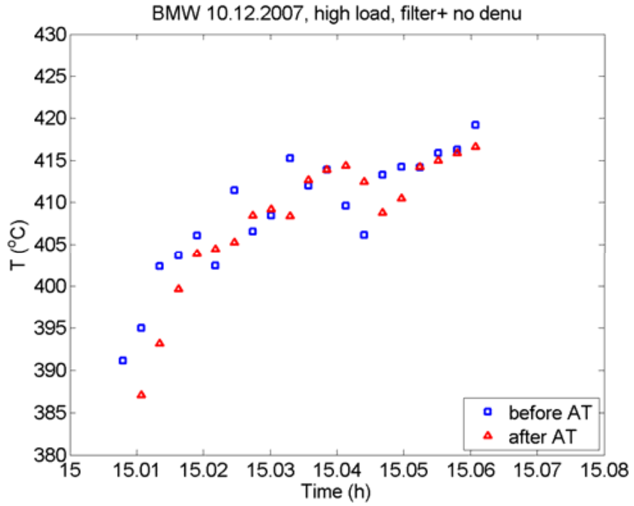
Results (PFC, denuder, BMW)

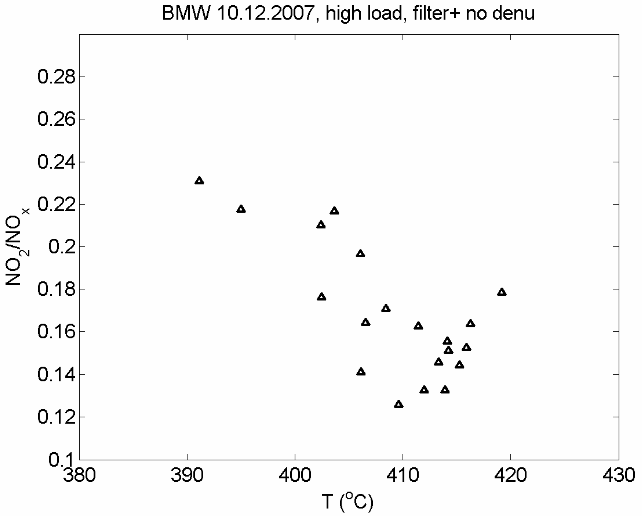


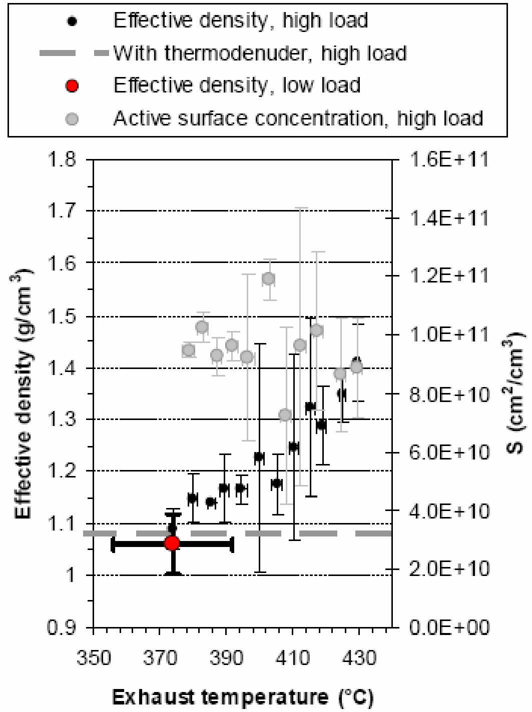




Results (PFC, no denuder, BMW)

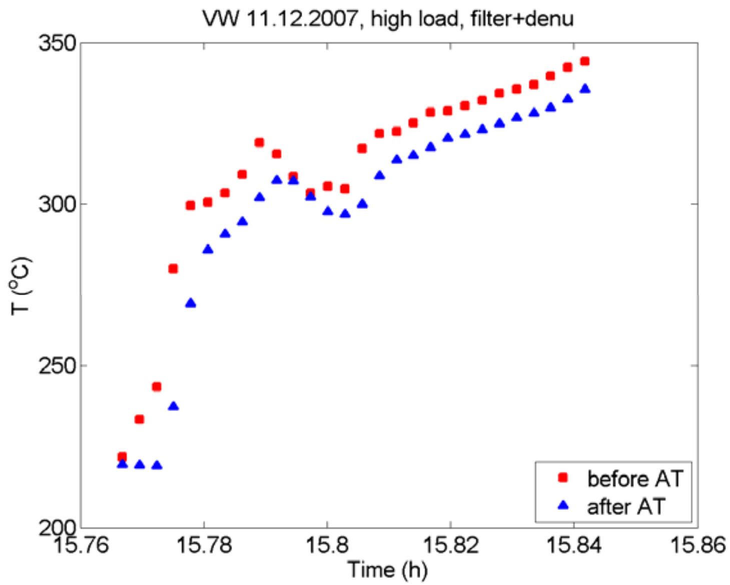


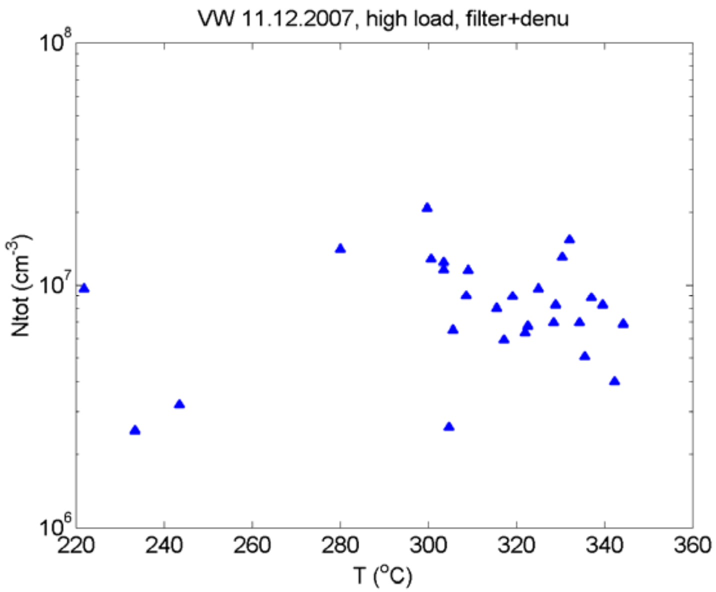


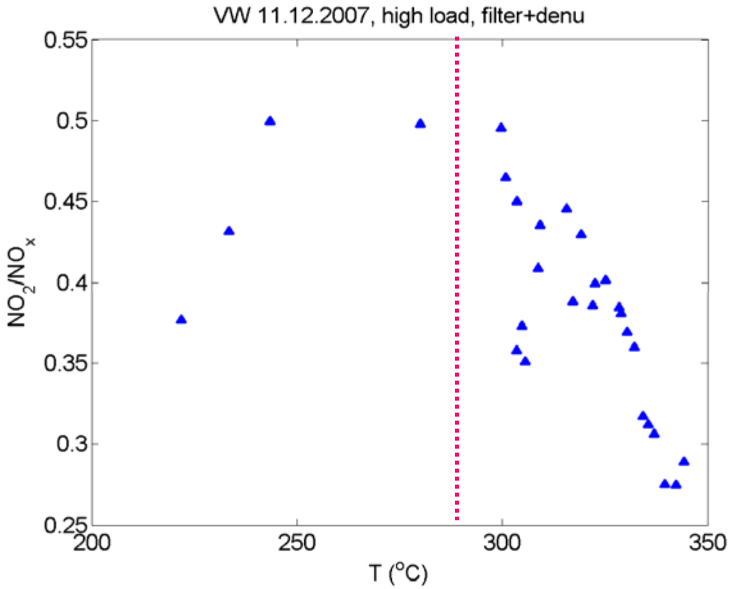


Rönkkö et al., 2008 submitted to EST

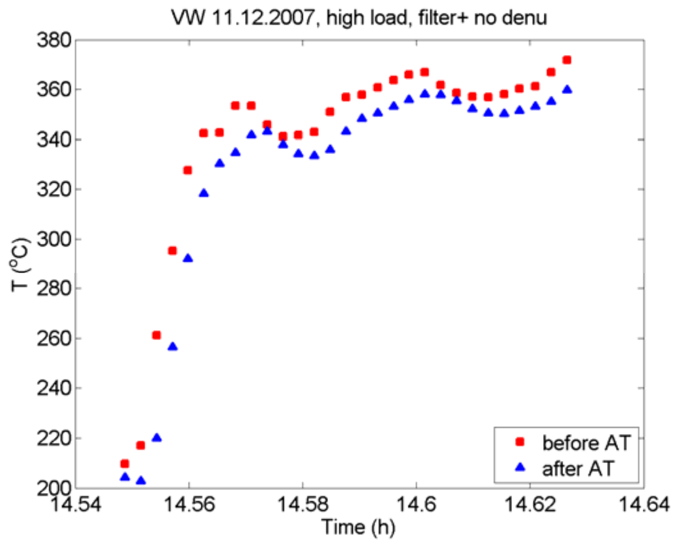
Results (PFC, denuder, VW Passat)



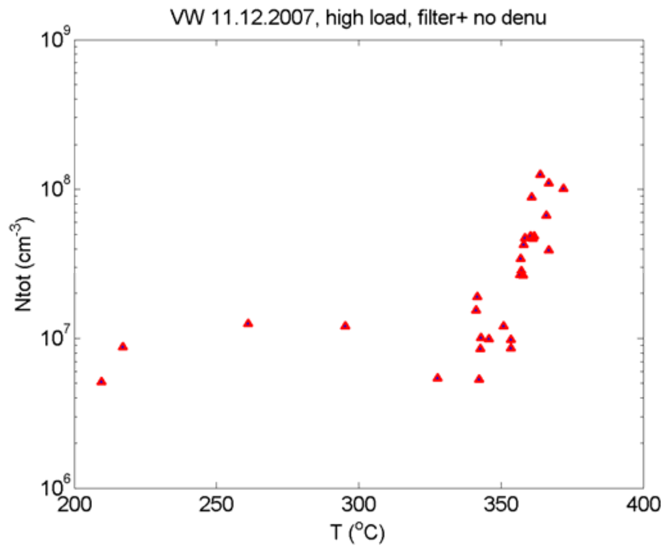




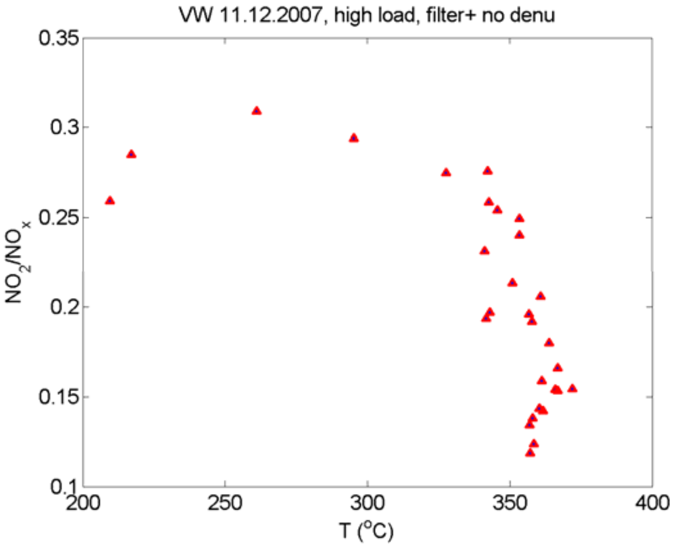
Results



VW 11.12.2007, high load, filter+ no denu
T (°C)
Time (h)
before AT
after AT



VW 11.12.2007, high load, filter+ no denu
Ntot (cm^{-3})
T (°C)



VW 11.12.2007, high load, filter+ no denu
NO_2/NO_x
T (°C)

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

This work was funded by the Ministry of Transport and Communications Finland