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Influence of fuel properties and aftertreatment techn. on particles in tailpipe and ambient air

4. ETH Conference on Nanoparticle Measurement, Zurich, 2000-08-08

Comparative Measurements of Particle Size Distribution - Influences of Motor Parameters and Fuels

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Abstract

The influence of fuel composition on particle emission was investigated using CEC-diesel and Swedish Class-1 diesel. The effects on particle size distribution are shown for different engine loads and exhaust gas recirculation ratios. Influences of the oxidation catalyst and the exhaust gas temperature are shown as well. Besides the well known effects on smoke number and particle mass emission Swedish Class-1 diesel turned out to produce also less particle number emission particularly within the medium load range if compared to CEC-diesel. To investigate particle formation under real dilution conditions measurements after tailpipe end have been carried out. A comparison between measurements in tailpipe using a standard mini dilution tunnel and in ambient air show good correlation in quality for size distribution.

1 Instrumetation for Particle Size Measurements

For measuring the number size distribution of the exhaust gas a dual differential particle spectrometer DDMPS (Instrument development of the University of Vienna Physics Group and GPR Inc., by Prof. G.P. Reischl) was used. This instrument consists of a common charger, 2 DMAs (Differential Mobility Analyzer) which are run in parallel with in-line FCEs (Faraday Cup Electrometer) for particle counting, a FCU (Flow Control Unit) and a Remote Control and Data Processing Unit. By using two DMAs a size range of 2 – 1000 nm mean particle diameter can be achieved. An overview of the system is shown schematically in fig. 1.

For diluting the exhaust gas a standard dilution tunnel at an average dilution ratio of 12 – 15 was used. The sample flow for the DDMPS was taken directly from the dilution tunnel. Because of the instruments high flow rates and its ability to be positioned close to the aerosol source no additional dilution is necessary.

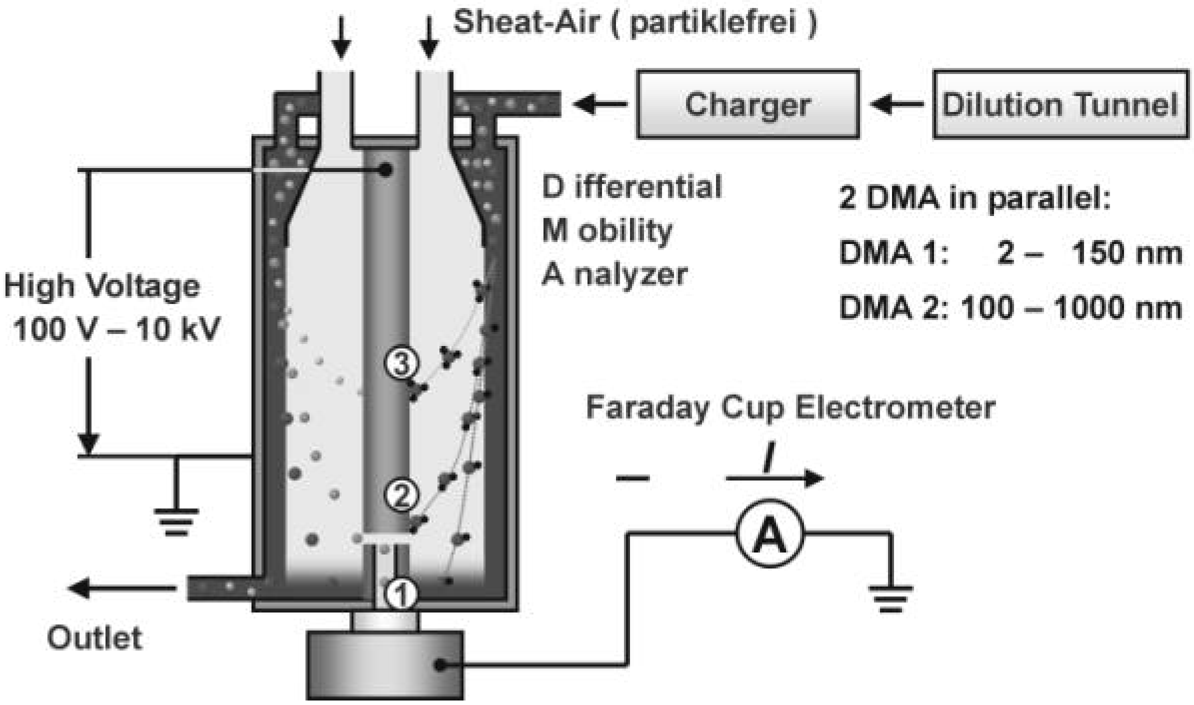

Fig. 1: DDMPS System Overview

2 Influence of Fuel Properties on Particle Size Distribution

To investigate the influence of fuel properties, particularly sulphur content, on particle size distribution CEC-reference diesel with a sulphur content of about 350 ppm and Swedish Class-1 diesel with a very low sulphur content of below 10 ppm have been chosen. Besides the differences in sulphur content Swedish Class-1 diesel has a lower aromatics content, too. Table 1 shows the most important fuel properties of both test fuels.

Property		CEC-Diesel	Swedish Class-1
Density	g/cm^3	0,8415	0,8111
cetan Number	-	50,5	51,5
sulphur content	%m/m	0,0350	0,0007
mono aromatics	% m/m	21,4	3,1
Polyaromatics	% m/m	5,7	0,1
total aromatics	% m/m	27,1	3,2
T_{95}	°C	349,0	288,5

Table 1: Properties of the test fuels.

The experiments with both fuels have been carried out on a engine test bed with a passenger car diesel engine with direct fuel injection.

Fig. 2 shows the particle size distribution downstream oxidation catalyst for both fuels at different engine loads.

At a mean effective pressure of 2 bar both fuels show nearly the same particle size distribution. If the engine load is increased to 4 bar bmep CEC diesel shows a strong increase of small particles resulting in a second mode with a maximum concentration that is about one order of magnitude higher than the first mode at bigger particle diameters. In contrast to that Swedish Class-1 diesel shows still a mono modal size distribution without increase at small particles. The increase of small particles in case of the CEC diesel can be attributed to nucleation of sulphuric particles downstream oxidation catalyst.

At higher loads the differences in particle size distribution between both test fuels diminish again, as shown for 12 bar bmep. In comparison to lower loads the size distributions are shifted towards smaller particle diameters as exhaust gas recirculation is switched off at high loads.

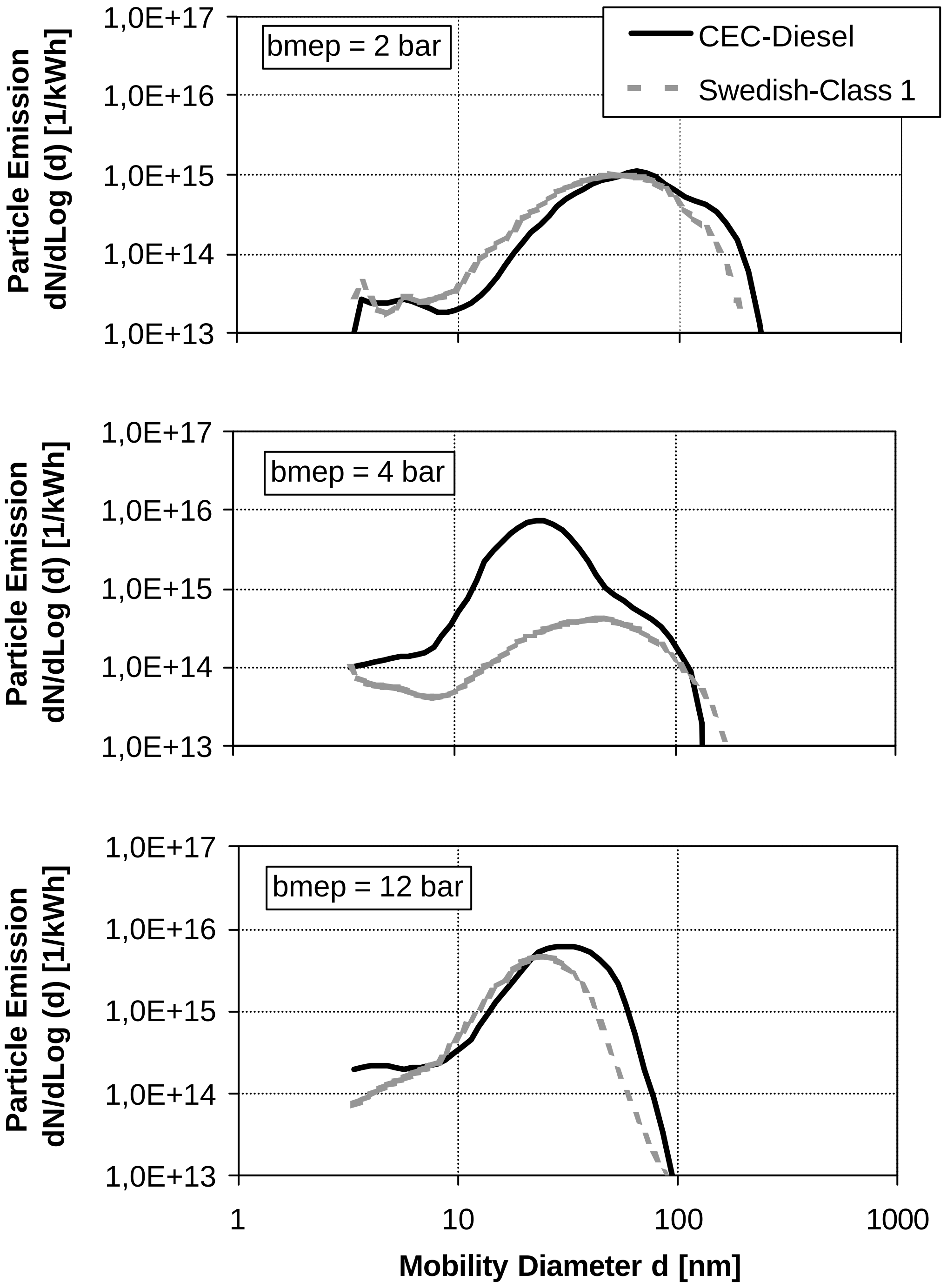

Fig. 2: Particle size distribution downstream oxidation catalyst for CEC-Diesel und Swedish Class-1 Diesel at n = 2000 rpm and different loads.

The total particle number emission downstream oxidation catalyst over mean effective pressure at n= 2000 rpm for both test fuels is shown in fig. 3. At low loads and low exhaust gas temperatures as well as at high loads above 10 bar bmep with high exhaust gas temperatures both fuels show nearly the same particle number emission. However, at medium load conditions CEC diesel affects a much higher particle number emission than Swedish Class-1 diesel.

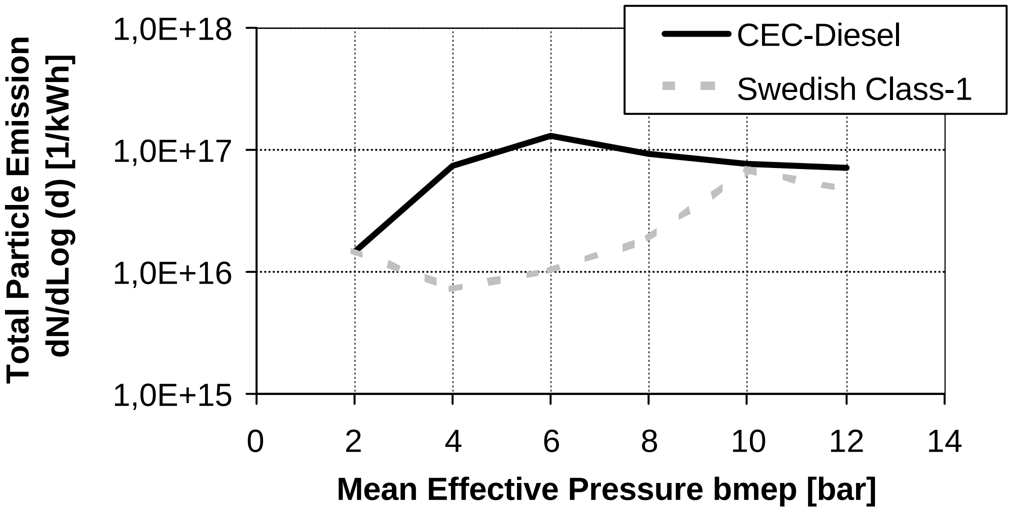

Fig. 3: Total particle number emission downstream oxidation catalyst over mean effective pressure at n= 2000 rpm; CEC-Diesel versus Swedish Class-1 Diesel.

3 Effects of Exhaust Gas Aftertreatment Devices on Particle Size Distribution

The effects of exhaust gas aftertreatment that are described in the following focus on oxidation catalysts. Fig. 4 shows a comparison of particle size distribution downstream oxidation catalyst and without oxidation catalyst for Swedish Class-1 diesel.

Without exhaust gas recirculation the particle emission consists of a high part of volatile components and unburned hydrocarbons resulting in a dominating mode with a peak between 20 and 30 nm. With oxidation catalyst these small particles are oxidized and the previously existing mode of small particles is completely removed.

With standard exhaust gas recirculation rate the particle concentration is about one order of magnitude higher than without EGR. Therefore the probability of particle accumulation is much higher and the particle size distribution shows only a single mode shape. With oxidation catalyst the particle number is decreased over nearly the whole size range for about 20 percent referring to the peak levels while the shape of the size distribution remains unchanged.

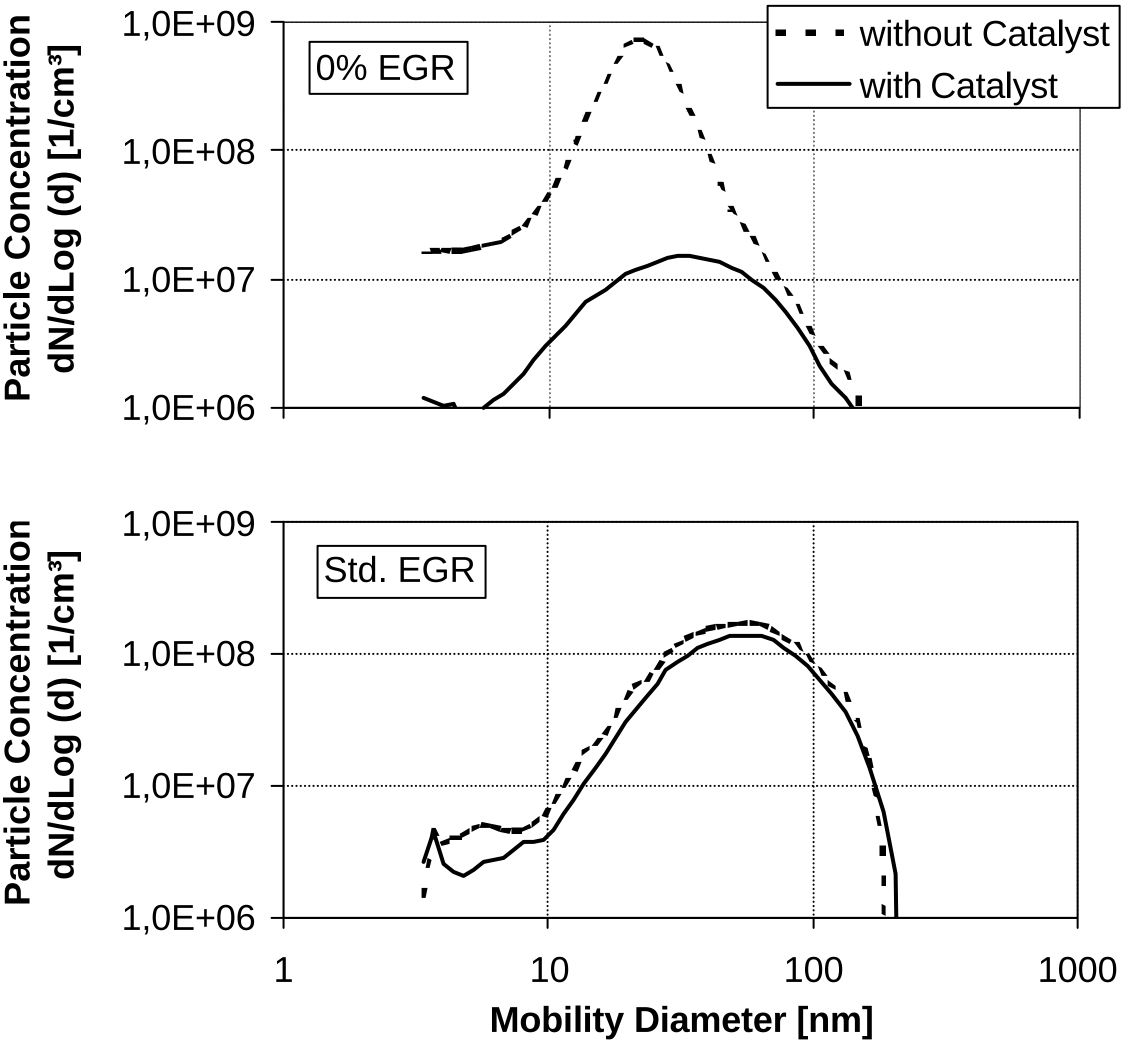

Fig. 4: Particle size distribution with and without oxidation catalyst at n = 2000 rpm and 4 bar bmep with and without exhaust gas recirculation.

Fig. 5 shows the effect of oxidation catalyst on particle size distribution at different engine loads for CEC-reference diesel. At low loads as 2 bar mean effective pressure and low exhaust gas temperatures the particle number is hardly effected over the whole size range.

If the critical temperature for sulphate production is passed, as it is the case for 4 bar bmep, a strong increase of small particles downstream oxidation catalyst can be found. Compared to fig. 2 the increase of small particles downstream the oxidation catalyst can be attributed to the fuel sulphur content.

At higher loads the differences in particle size distribution with and without oxidation catalyst diminish again, as shown for 12 bar bmep.

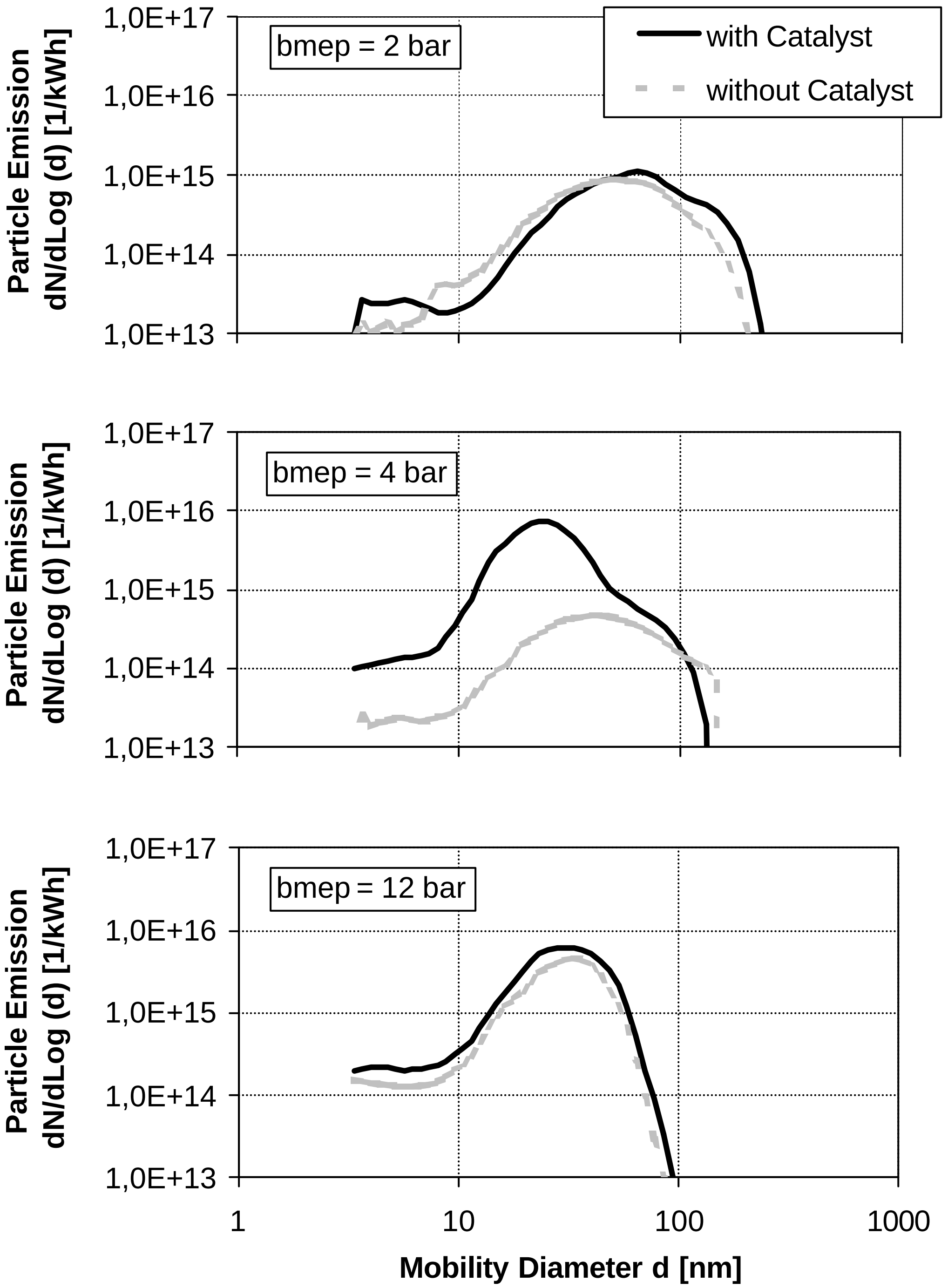

Fig. 5: Particle size distribution with and without oxidation catalyst at n = 2000 rpm and different loads; CEC-Diesel.

The effect of exhaust gas temperature on particle size distribution downstream oxidation catalyst is shown in fig. 6. The temperature was varied from 300 to 385 °C, while the engine was run under steady conditions. Above about 320 °C sulphuric particles with a mobility diameter of about 10 nm can be found. With higher temperatures the number of these particles increases and their mode is shifted towards bigger diameters through coagulation.

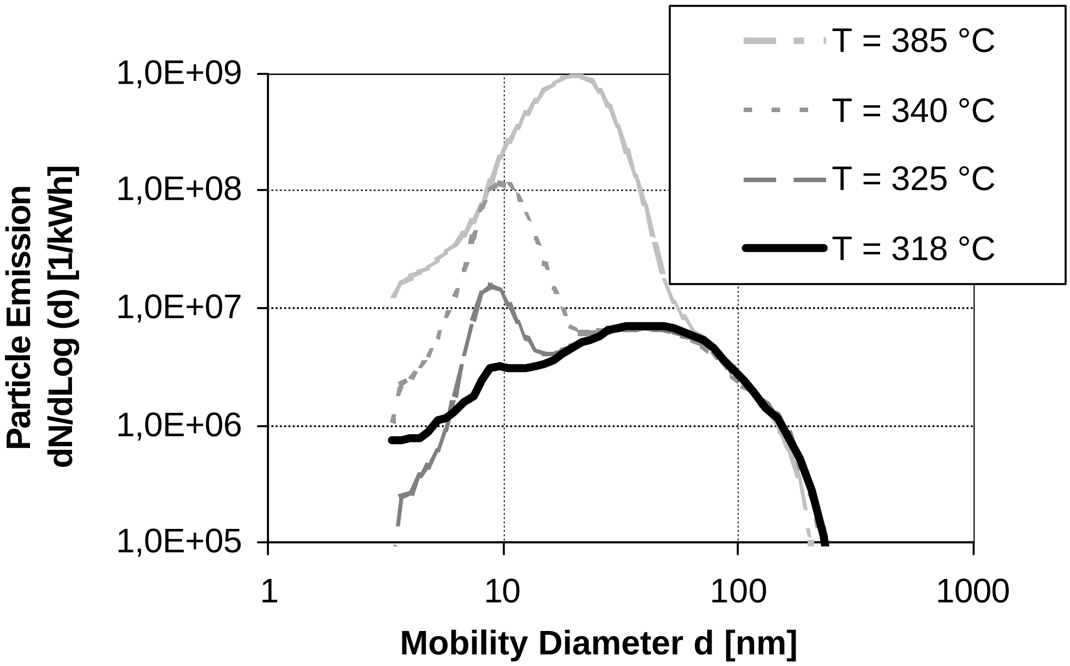

Fig. 6: Particle size distribution downstream oxidation catalyst at the same engine load and different exhaust gas temperatures.

4 Particle Formation under Real Dilution Conditions

The experiments described in the following have been done to compare the dilution process as it happens under real conditions and in the dilution system used at the engine test bed. For this purpose measurements at different distances from the tail pipe end have been carried out. A schematic of the test arrangement is shown in fig. 7. The sampling positions have been chosen in different distances up to 3 m from the tail pipe end and different levels. A tarmac ground and a blower are to simulate driving conditions.

In Fig. 8 particle size distributions at sampling positions 1, 2, 3, 5 and 7 are compared to measurements with the dilution system, a standard mini dilution tunnel, MDT. All measurement after the tail pipe have been done without any dilution.

With increasing distance the concentration decreases due to dilution but the size distribution remains unchanged with the same shape as it has been found using the MDT.

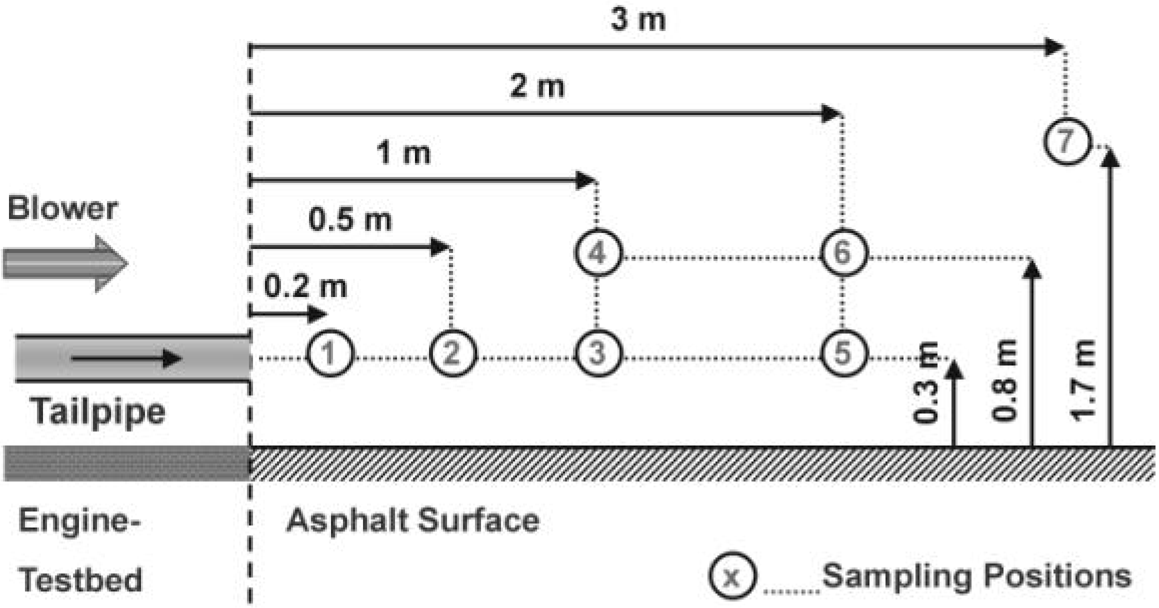

Abb. 7: Test arrangement for particle sampling in ambient air after tailpipe end.

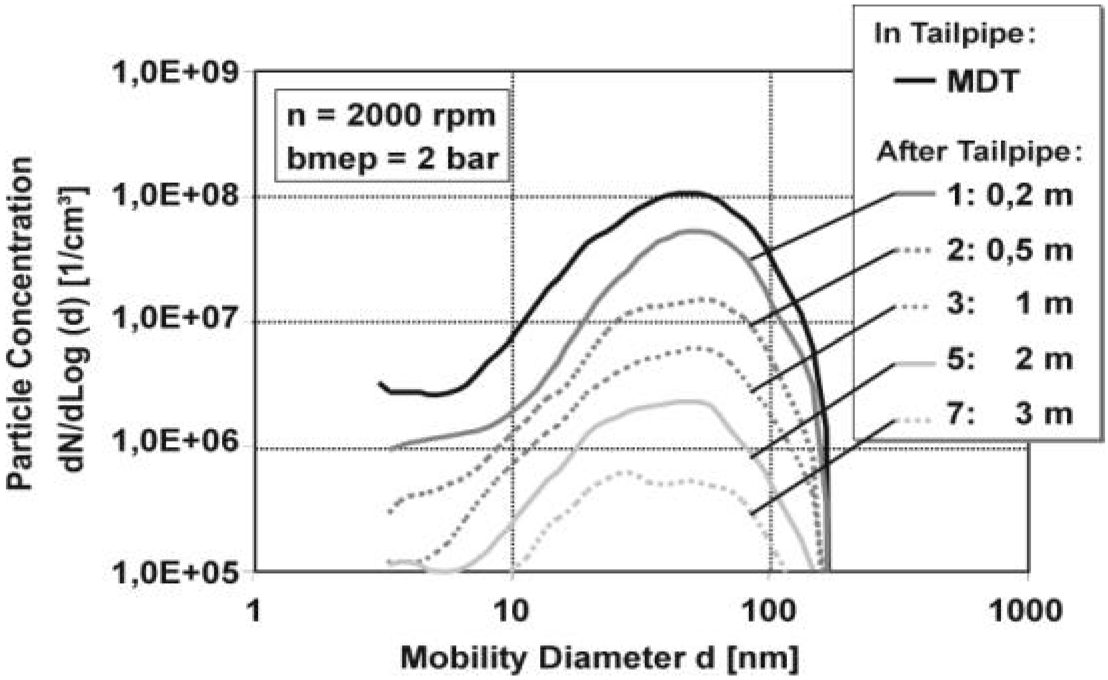

Abb. 8: Particle size distribution at different sampling positions at n = 2000 rpm and 4 bar bmep.

At a higher engine load without exhaust gas recirculation, fig. 9, the MDT measurement shows a small nucleation mode. In close distance from the tail pipe end with nearly no dilution this nucleation cannot be found. At further distances, however, the same nucleation mode as with MDT can be seen. If the dilution factor would be taken into account the size distributions would be congruent.

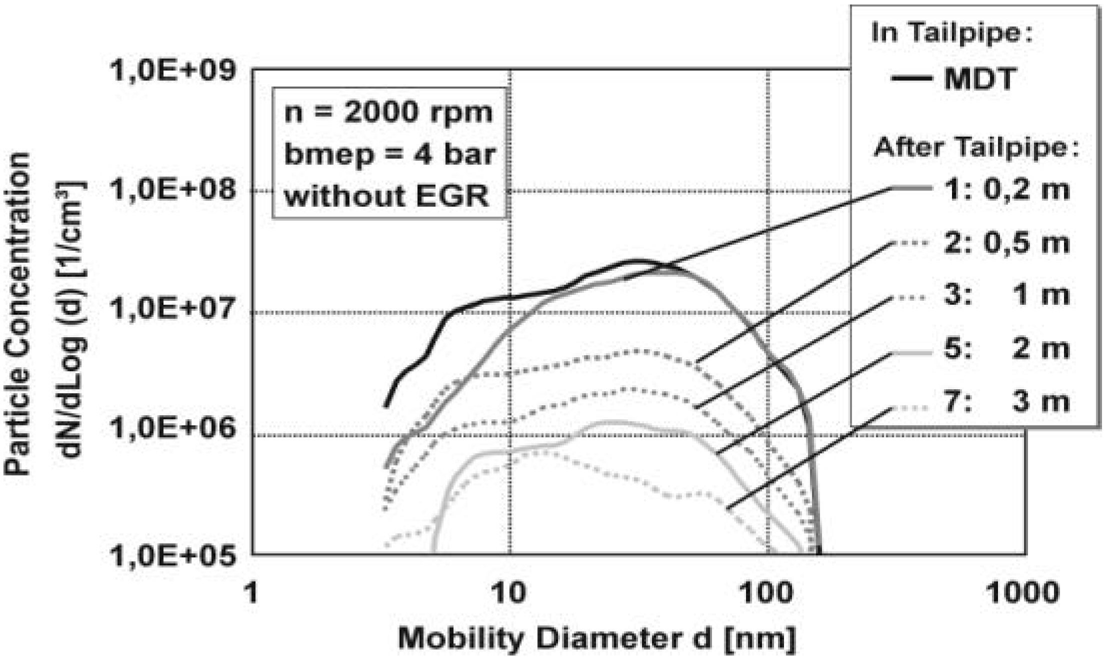

Abb. 9: Particle size distribution at different sampling positions at n = 2000 rpm and 4 bar bmep.

An example for higher engine load and therefore higher exhaust gas temperature can be seen in fig. 10. With MDT a nucleation mode below 10 nm can be found. Particle formation during dilution in the ambient air shows no nucleation mode at clear distances to the tailpipe end. However, a strong nucleation process starts about one meter after the tail pipe end and remains till the last sampling position at 3 m.

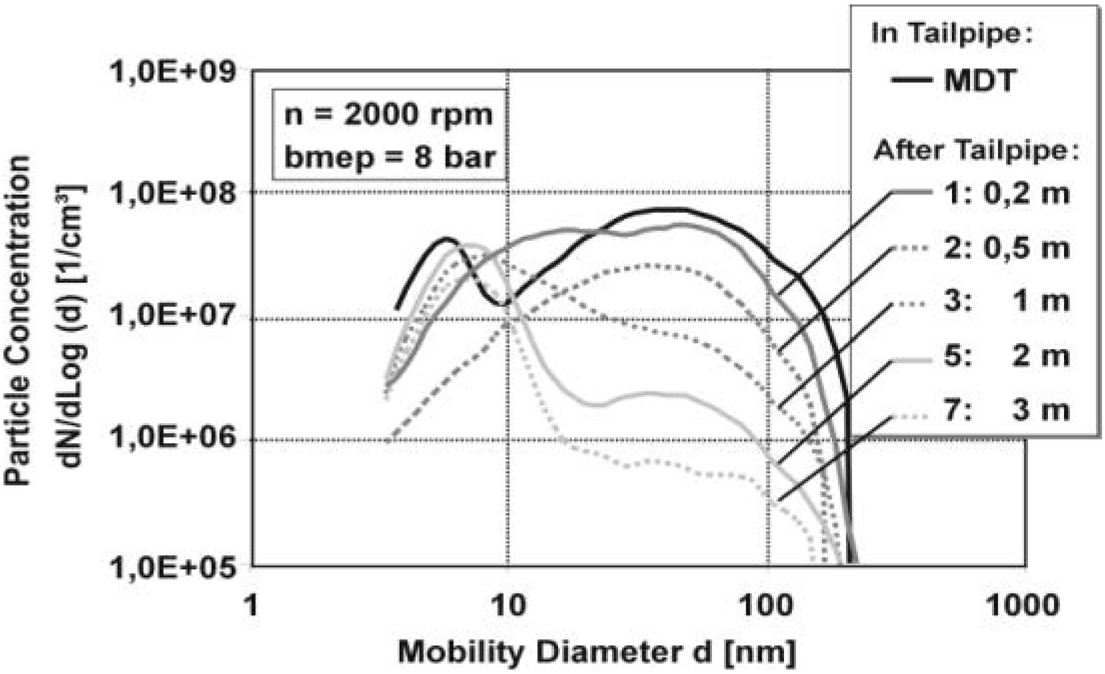

Abb. 10: Particle size distribution at different sampling positions at n = 2000 rpm and 8 bar bmep.

5 Conclusions

Fuel properties show a significant effect on particle size distribution.

Due to its higher sulphur content CEC-Diesel causes a higher emission of small particles at medium engine loads. At higher loads and therefore higher exhaust gas temperatures these differences can not be found.

Oxidation catalysts reduce particles, especially from unburned hydrocarbons. Depending on the fuel sulphur content they effect the origin of small sulphate particles.

A comparison between measurements in tailpipe using a standard mini dilution tunnel and in ambient air show good correlation in quality for size distribution.