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Nanoparticle formation in diesel vehicle exhaust: a comparison of laboratory and chasing experiments

Nanoparticle formation in diesel vehicle exhaust: A comparison of laboratory and chasing experiments

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Introduction

The currently ongoing public debate on the emission of particulates is focused around air quality and health concerns. Sources of particulates include industrial processes, road transport, and natural emissions from primary sources and secondary particle formation. Regarding diesel particle emissions there are still large uncertainties during the measurement of particle number/size. It is clear that diesel particles consist of EC, OC, sulfuric acid, and some metal ash. The largest uncertainty is the formation of ultrafine particles of 10-20 nm size.

Open questions include:
How does exhaust dilution effect PM size distribution?
What is the effect of the fuel sulfur and oxidation catatalyst?

Abstract

Exhaust particle size distributions from a diesel passenger car operated on a chassis dynamometer were measured with a scanning mobility particle sizer (SMPS). The exhaust was either sampled after secondary dilution from the dilution tunnel, or was directly taken from the tailpipe using two mini-diluter systems. The influence of the dilution ratio, the relative humidity of the dilution air, and the residence time of the diluted exhaust has been studied with a special emphasis on the formation of condensed particles.

One important question is how well the exhaust dilution in the emission laboratory reflects real atmospheric dilution? To address real world dilution the Ford Mobile Laboratory (FML) was used. This is a "state of the art" laboratory based on a Ford Transit. While carefully following vehicles under controlled conditions, air from their exhaust plume is continuously sampled and analyzed inside the mobile laboratory. Exhaust particle size distribution data together with exhaust gas concentrations are collected and is compared with measurements obtained in the emission test laboratory.

The test vehicle is a current production turbo charged DI Diesel passenger vehicle with oxidation catalyst which was operated with 350 ppm fuel sulfur. To investigate the effect of the oxidation catalyst and fuel sulfur some chasing experiments were conducted with low (10 ppm S), or with normal S fuel and without oxidation catalyst. Significant effects on the nucleation mode particles were observed, depending on the presence of fuel sulfur and the oxidation catalyst.

Dynanometer exhaust dilution & sampling

Fig. 1: Dynanometer exhaust dilution & sampling. For direct tailpipe sampling two ejector-pump diluters or a rotating disk diluter (Matter Engineering AG) were used.

Effect of residence time

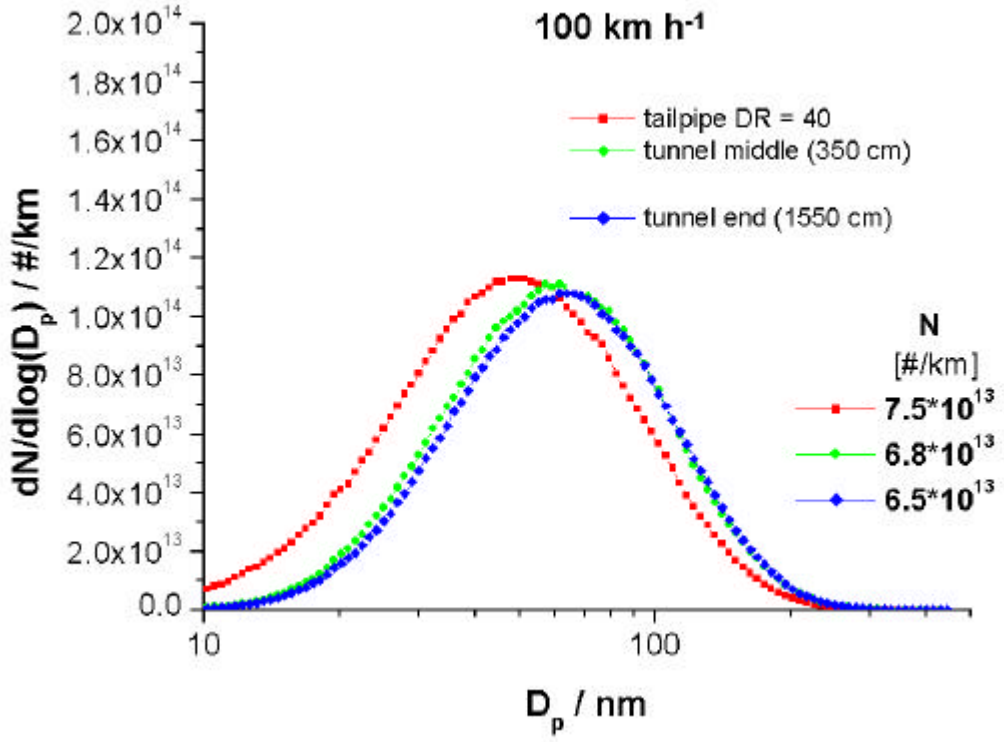

Fig. 2 Comparison of particle size distribution measured at three sampling location with the Matter diluter. The diesel vehicle was running at constant speed of 100 km h^{-1}. The Matter diluter was set to a dilution ratio of 1:40. At the tunnel the total dilution ratio was 1:440.

Effect of residence time

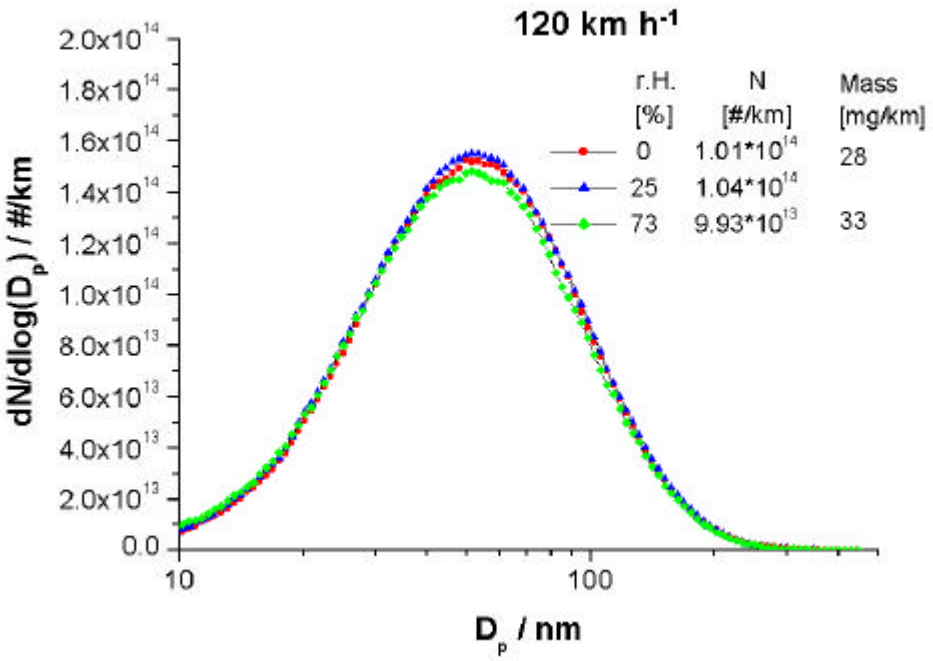

Fig. 3: Comparison of particle size distribution measured with the Matter diluter at the tailpipe of the diesel vehicle. The short sampling line was heated and the exhaust was diluted with humidified synthetic air at the given relative humidity (r.H.) values

On-road chasing of exhaust plume

Fig. 4. Chasing of exhaust plume with Ford Mobile Laboratory

Exhaust chasing of diesel vehicle

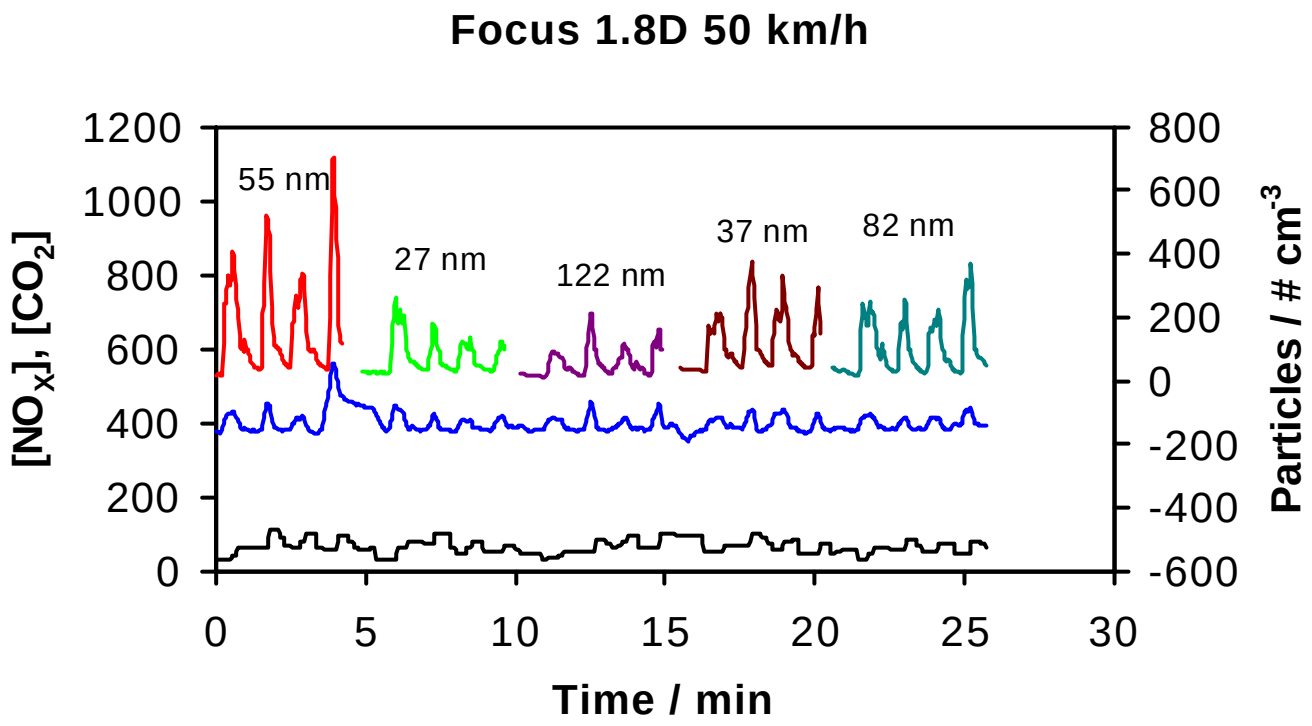

Fig. 5. NO_x, CO_2 and particles measured at a fixed SMPS size bin while drive in and out of the exhaust plume of the diesel test vehicle.

PM size distribution during chasing of diesel vehicle

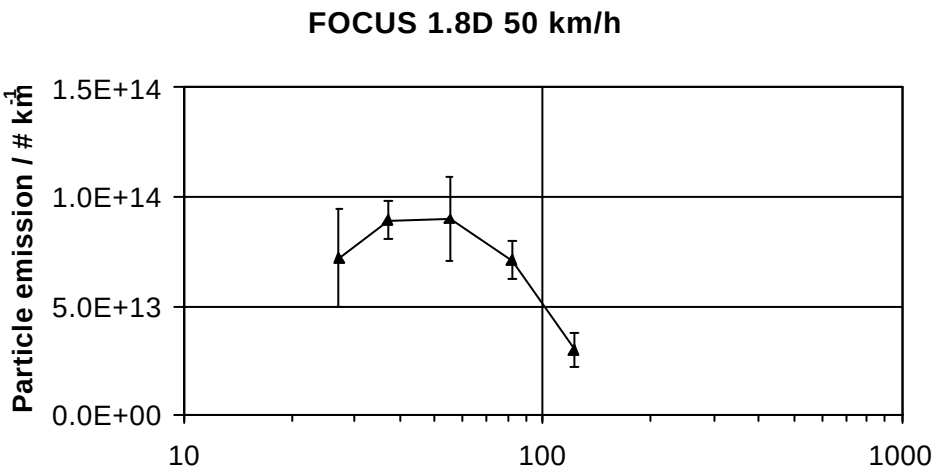

Fig. 6. Constructed size distribution from chasing experiments. The dilution ratio is calculated from the measured NO_x and CO_2 concentration and the known NO_X and CO_2 emission at constant speed.

PM size distribution during chasing at different speeds

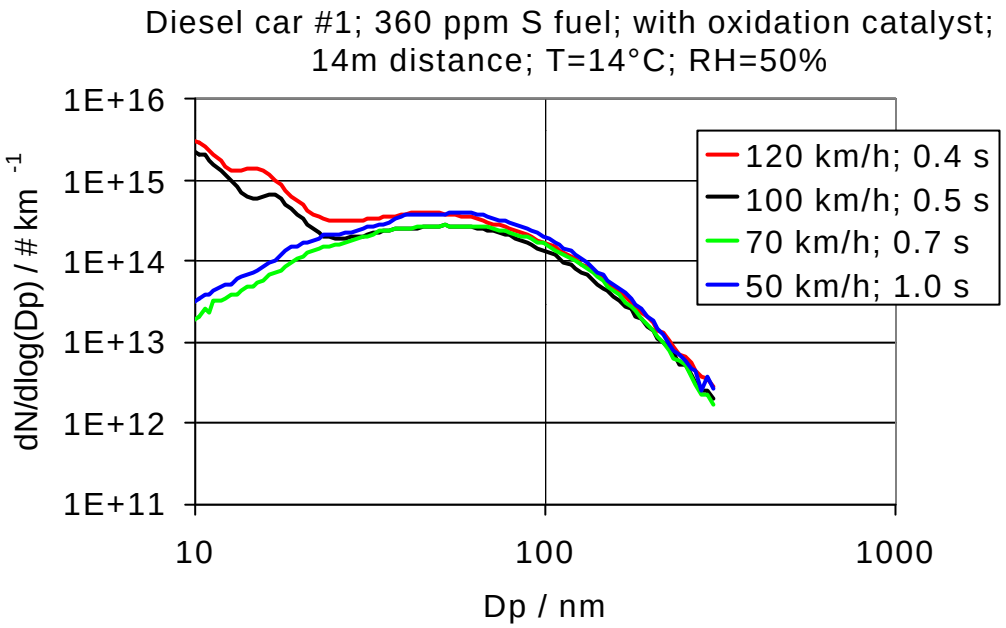

Fig. 7: Size distributions measured at different speeds in the exhaust plume of the test vehicle. running on 360 ppm S fuel and oxidation catalyst.

PM size distribution during at different speeds at dynanometer

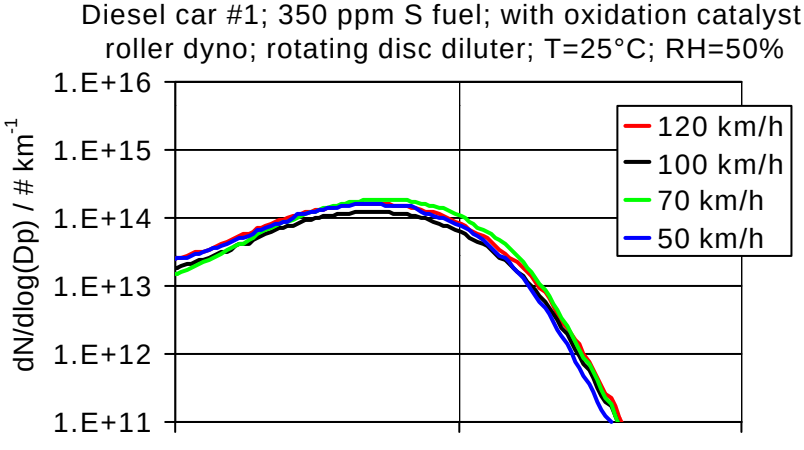

Fig. 8: Same test vehicle as Fig 7 operated at different speeds at chassis dynanomter. No nucleation mode particles were observed with rotating disc diluter.

PM size distribution during chasing at different speeds: no oxidation catalyst

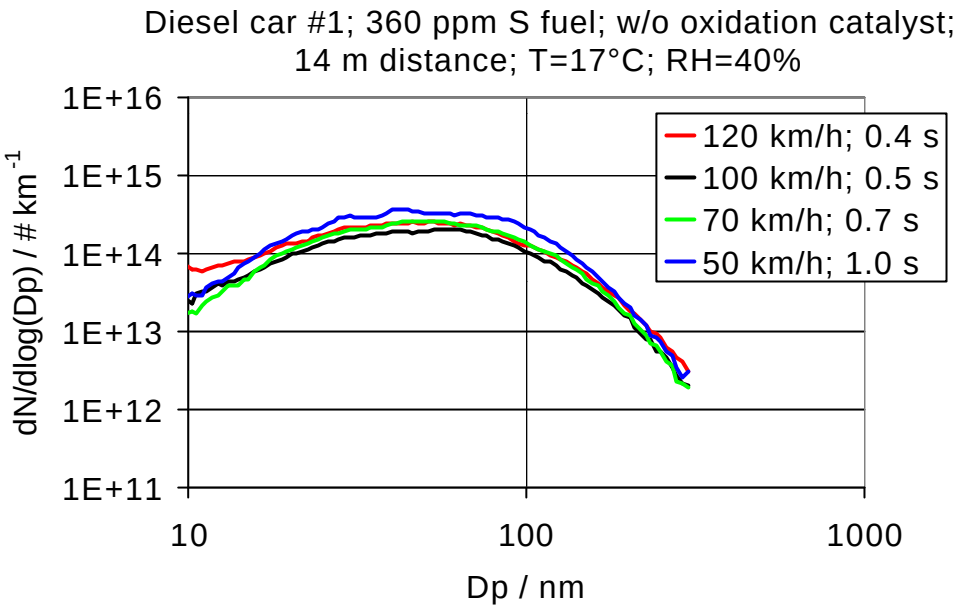

Fig. 9. PM size distributions measured in exhaust plume of test vehicle with 360 ppm fuel S and no oxidation catalyst.

Fuel-S and oxidation catalyst effect

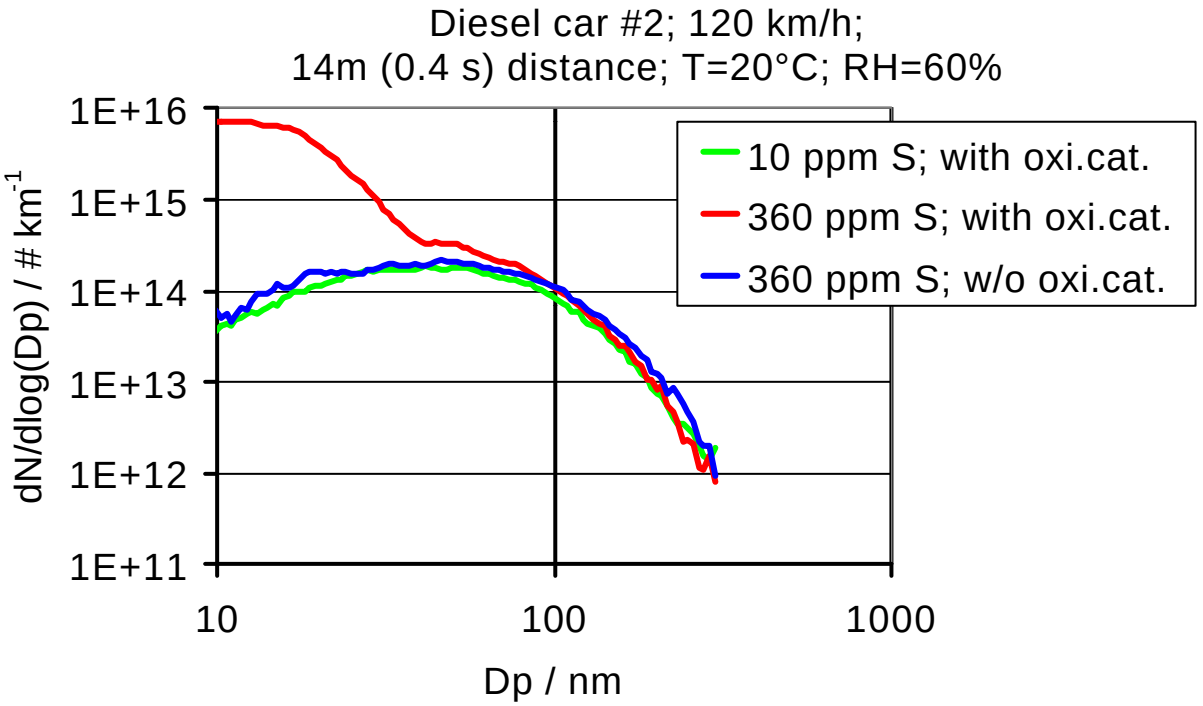

Fig. 10. PM size distributions measured in exhaust plume of test vehicle with different S fuel, with and w/o oxidation catalyst

Time evolution of nucleation mode particles

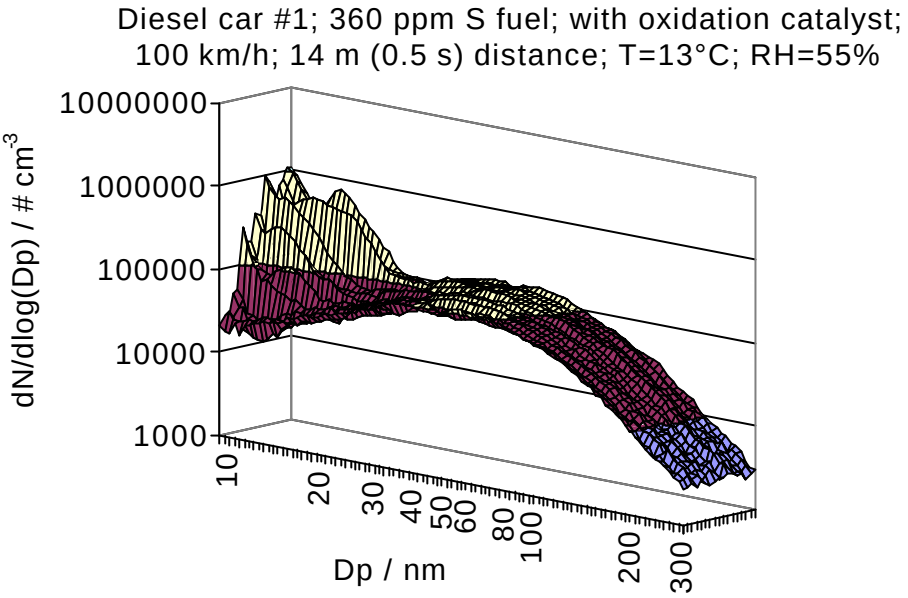

Fig. 11. Evolution of nucleation mode in PM size distribution during 40 min chasing at 100 km h^{-1}.

Evolution of nucleation mode particles and vehicle parameters

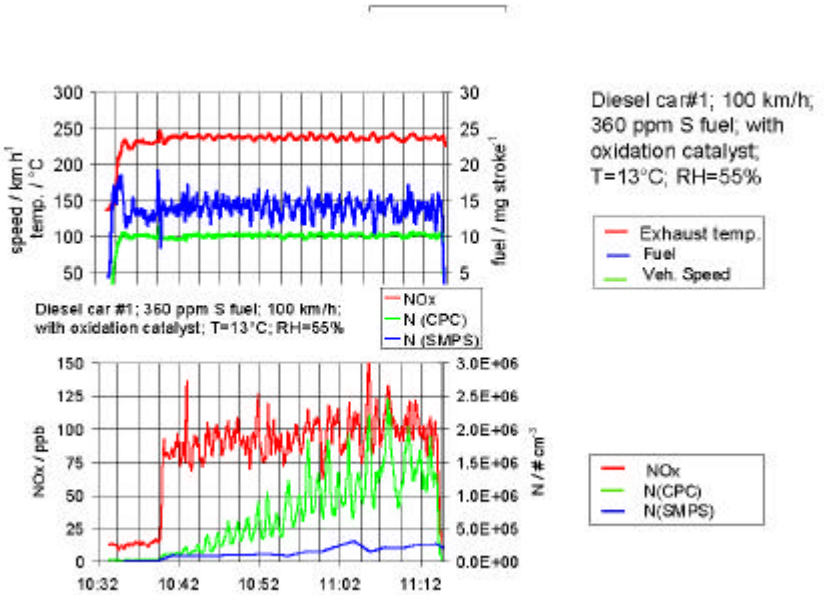

Fig. 12. Evolution of number emission (CPC and integrated SMPS) in PM size distribution during 40 min chasing at 100 km h^{-1} and fuel consumption, exhaust temperature and vehicle speed.

Summary

- Diesel vehicle particle size distributions measured at the dynanometer were unimodel (340 ppm S; with oxidation cat)
- Number/size distribution varied depending on sampling condition
- Good agreement of tailpipe sampling and exhaust chasing for soot mode particles
- Nucleation particles occur during atmospheric dilution only at 100 and 120 km h^{-1}, if 360 ppm S fuel and oxidation catalyst are used
- Using 10 ppm S fuel, no nucleation particles were observed