N. Rojas
University Leeds
Leeds
United Kingdom

Deposition/Release of particles in a diesel oxidation catalysts, effect of EGR on cold start

DEPOSITION AND RELEASE OF PARTICULATE MATTER DURING COLD START AND EFFECT OF EGR – Néstor Y. Rojas, PhD Student, University of Leeds

4th International Conference on Nanoparticle Measurement. ETH Zürich, August 7-9, 2000.

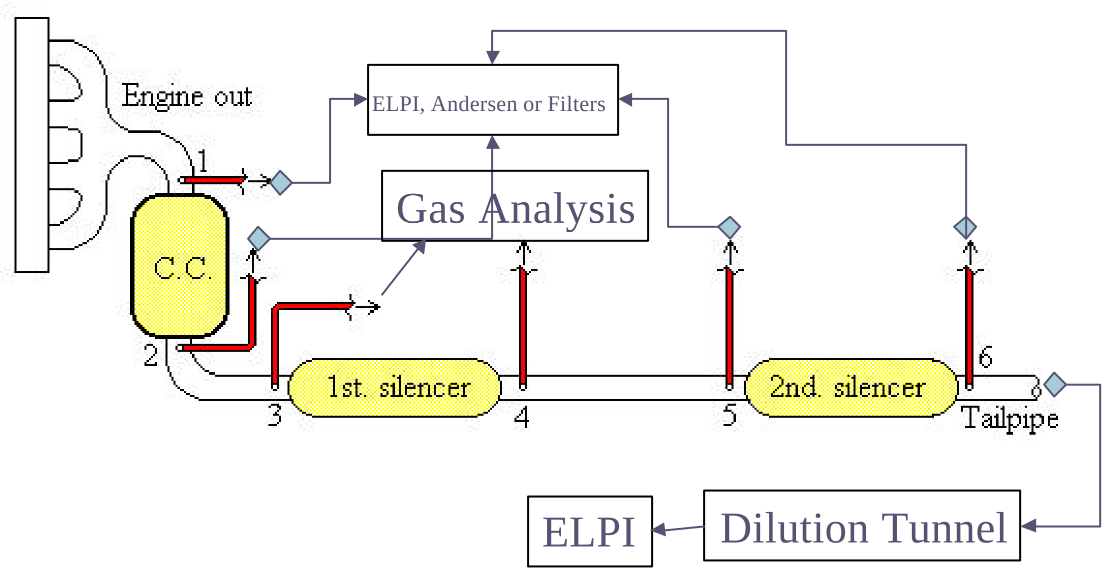
PURPOSE

This is a presentation of the results obtained at the Department of Fuel and Energy of the University of Leeds as a part of the research on Diesel Particulate Emissions under the supervision of G.E. Andrews and A.G. Clarke, and sponsored by the EPSRC and Ford Motor Company.

Problem: unpredictable, sudden release of visible clouds of particles from the exhaust system of diesel-powered vehicles.

Conditions: Cold start and fast acceleration.

Experimental set-up:



Engine: Ford 1.8L IDI Turbocharged Intercooled Diesel Engine. Exhaust system identical to the one installed in its commercial version.

Particulate measurement techniques include: a)Particulate Mass Concentration by the Heated SAE Smoke Number measurement, using glass fibre filters to collect particulate mass at 52^{o}C, directly from the exhaust; b) Particle Size Distribution by using Andersen Impactors and ELPI.

Previous published results: SAE papers 2000-01-0508, -0511 and -0514.

PARTICLE DEPOSITION AND RELEASE (SAE Paper 2000-01-0508)

The initial **Mass Concentration** measurements showed that the previous operational history of the engine had a strong influence on the catalyst performance, greater than the influence of the initial temperature of the catalyst. A previous conditioning at idle generates deposits along the exhaust system, which are released during cold start, resulting in a different behaviour from a previous conditioning at high speed and load that "cleans" the exhaust.

The catalytic converter that is installed in the system acted as a particulate trap during cold start and its efficiency was higher at idle and low speed conditions than at medium speed conditions. Downstream of the catalyst, particulate mass deposits were released at all conditions studied, as an overall result from accumulation and release through both two silencers. In that section, release of particulate from the first silencer and deposition in the second was the general trend observed during cold start.

ENGINE OUTLET CHANGES DURING FAST ACCELERATION (SAE Paper 2000-01-0511)

Measurements of **Particle Number Concentration and Size Distribution** during *fast acceleration* were made using the whole exhaust and a dilution tunnel operated to keep the dilution ratio constant, confirming that big particles in the range 2-8 nm were released from the walls of the exhaust system during transient operation. These particles were and important feature of the mass distribution but not of the corresponding number distribution.

PARTICLE SIZE DISTRIBUTION CHANGES ALONG THE EXHAUST SYSTEM DURING COLD START (SAE Paper 2000-01-0514)

Measurements with the ELPI along the exhaust system during cold start demonstrated the blow out of particulate previously deposited at idle and showed a much closer picture of what is happening along the exhaust system on a second-by-second basis. A large release of particulate mass occurred during the first 20 seconds of the cold start, which was due mainly to big particles whose number was low. A maximum in particle number was observed afterwards. Mass and number of particles behaved, therefore, in a somewhat different way, owing to differences in the size ranges involved in the events.

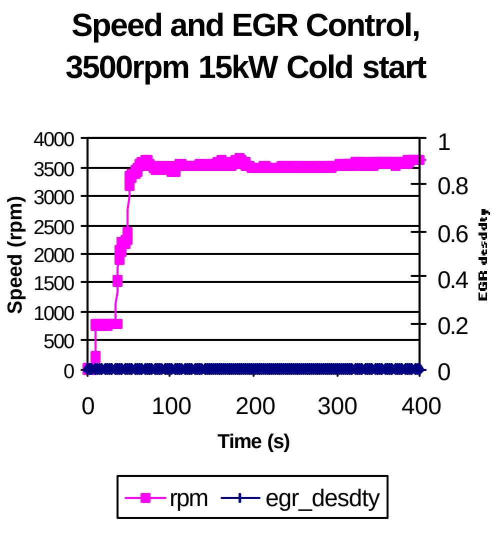
Based on numbers, the catalyst released particles at first and after its light-off it stores and/or oxidises particles. The silencers operated out of phase with each other, when one was storing the other was releasing particles.

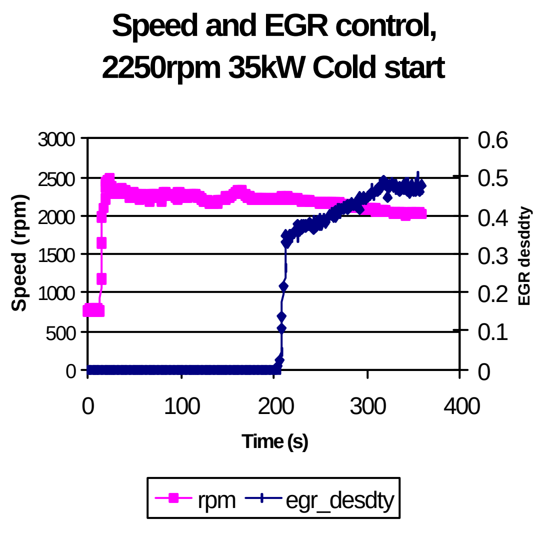
Based on mass, the catalyst released particles during the first 30 seconds. Release from both silencers was observed after the catalyst lit off. After two minutes no further accumulation or release was observed.

RECENT RESULTS

Two engine operating conditions were tested: 3500rpm@15kW for high exhaust gas speed; and 2250rpm@35kW for high load and therefore high exhaust gas temperature, leading to a higher temperature difference between gas and walls.

Different conditions lead to different EGR operation.

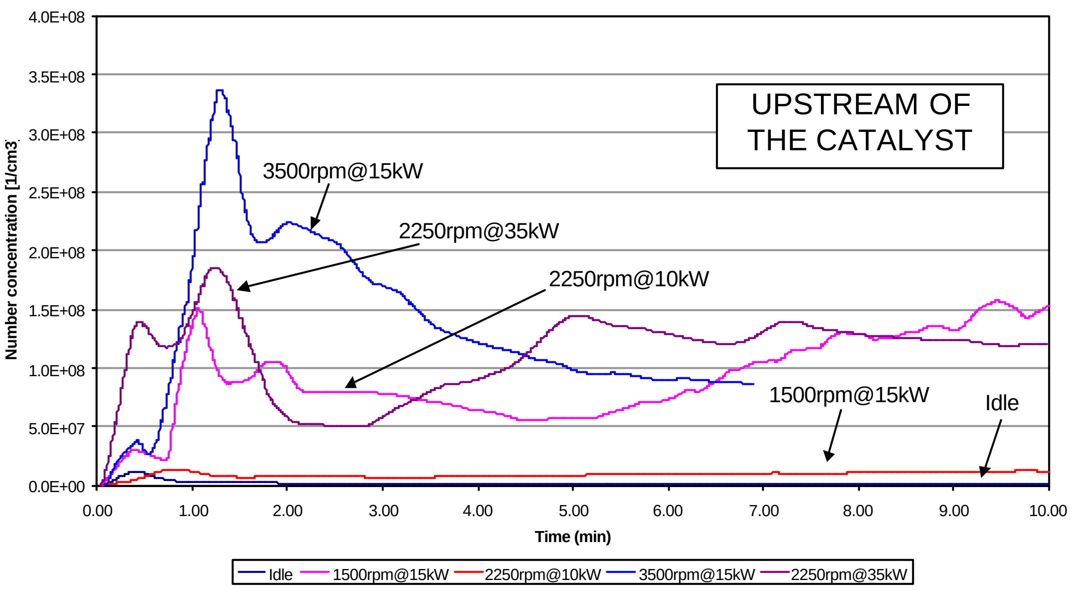




GENERAL CHARACTERISTICS OF NUMBER CONCENTRATION VS. TIME AND EGR EFFECT

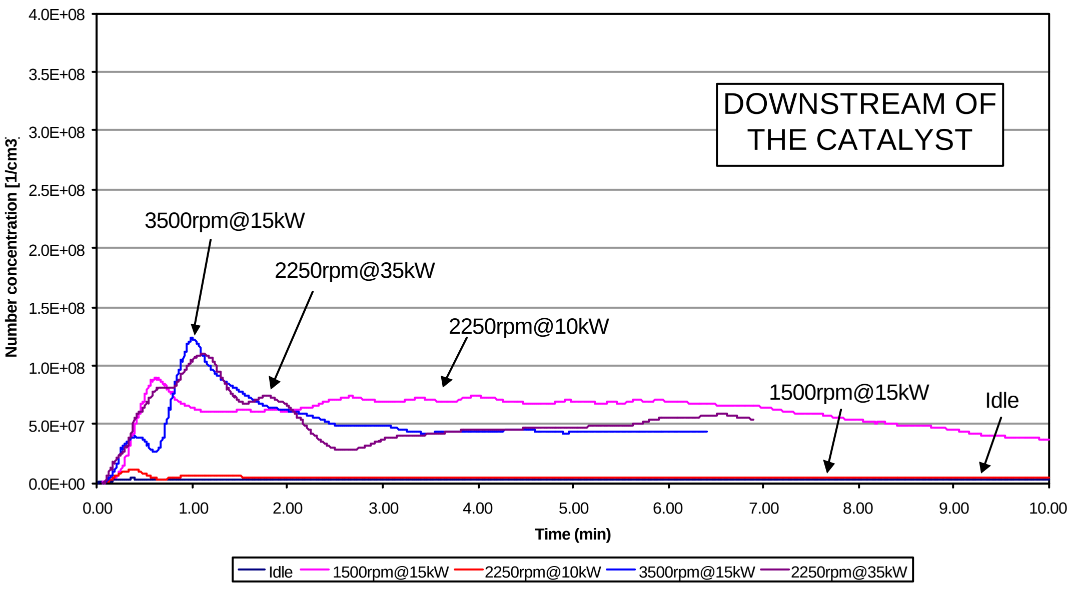
Cold start emissions general characteristics in number concentration with time: a) a first peak corresponding to mass release that occurred in the first 30 seconds; followed by b) a peak by number between one and two minutes; and c) a further decrease. Opening the valve at high load condition showed a strong increase in particle number and mass emissions at all four sampling points.

Number concentration during cold start at different operation conditions

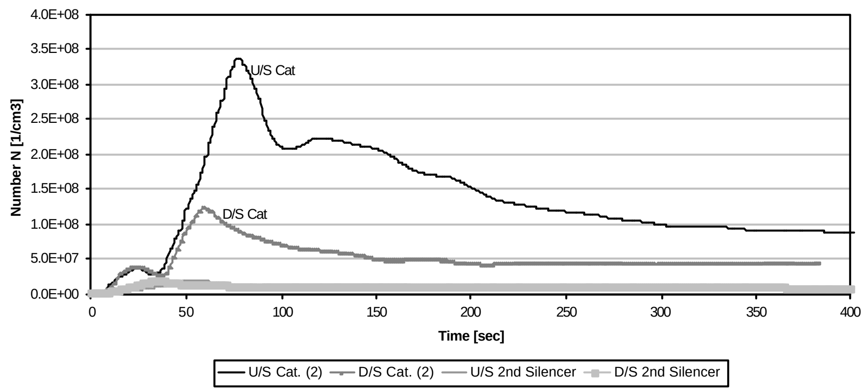


Compared to previous results, number concentration emissions at 2250rpm@35kW upstream of the catalyst resulted comparable to those at the same speed but 10kW power, whereas it was much higher when the speed was increased to 3500rpm keeping power at a medium level, 15kW. Downstream of the catalyst, number concentration levels at both high speed and high load conditions were comparable to those at 2250rpm@10kW.

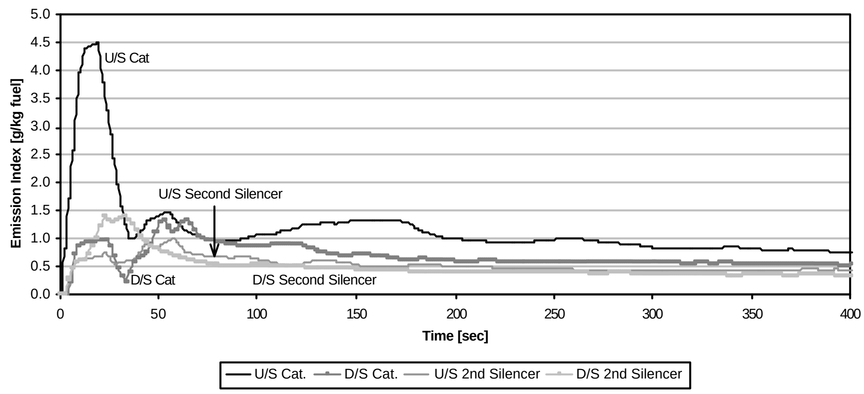
Number concentration during cold start at different operation conditions



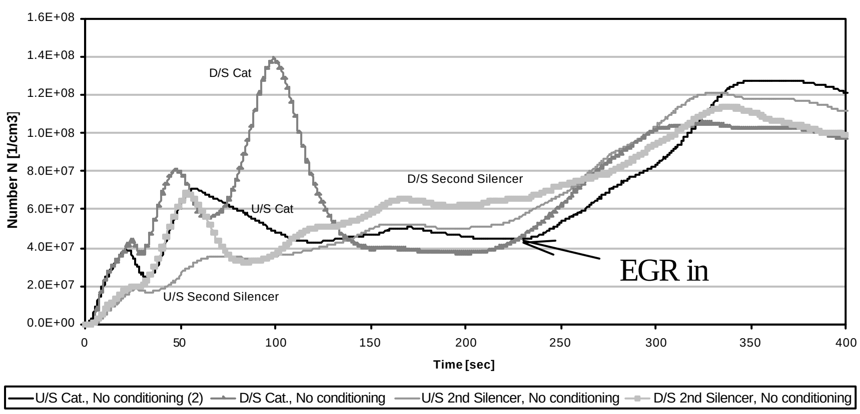
Total Particle Number Concentration during Cold Start, 3500rpm@15kW
With Idle Conditioning



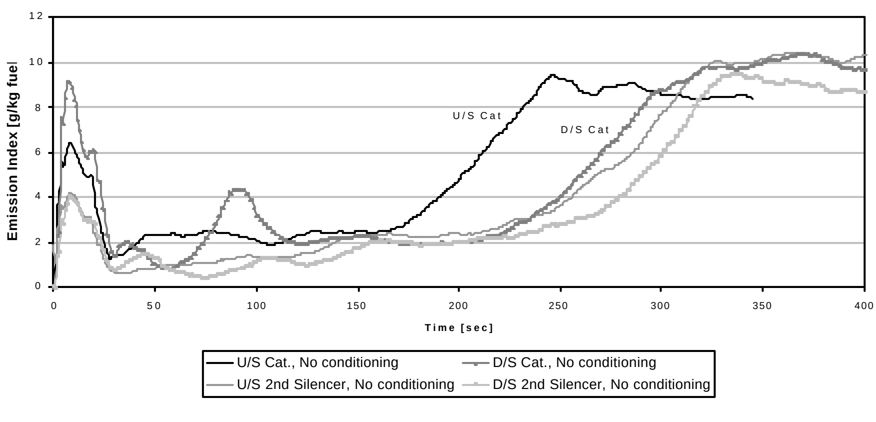
Emission Index Concentration during Cold Start, 3500rpm@15kW
With Idle Conditioning



Total Particle Number Concentration during Cold Start, 2250rpm@35kW



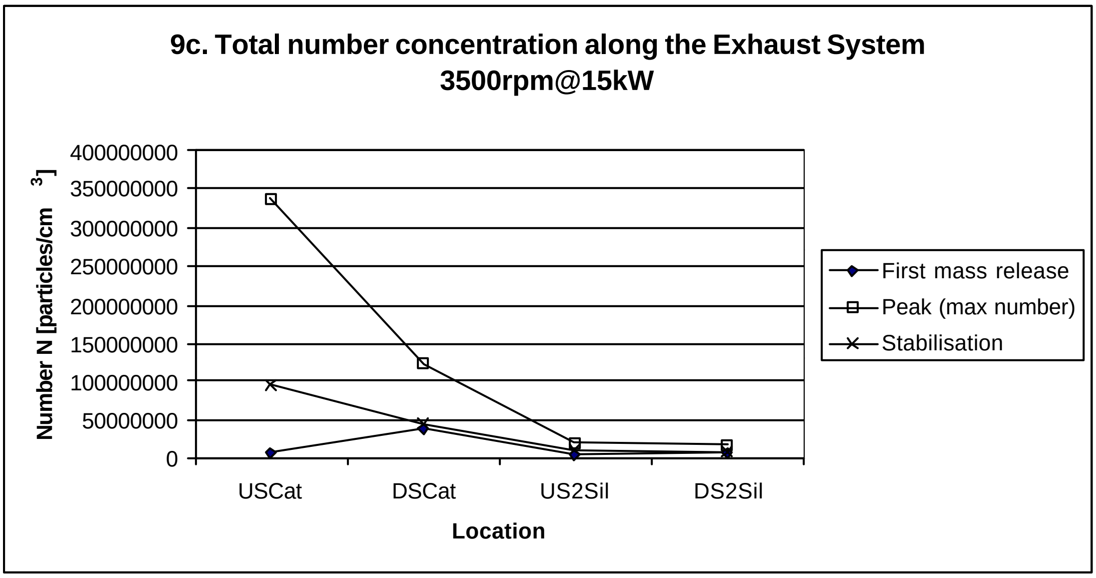
Emission Index Concentration during Cold Start, 2250rpm@35kW
No Idle conditioning

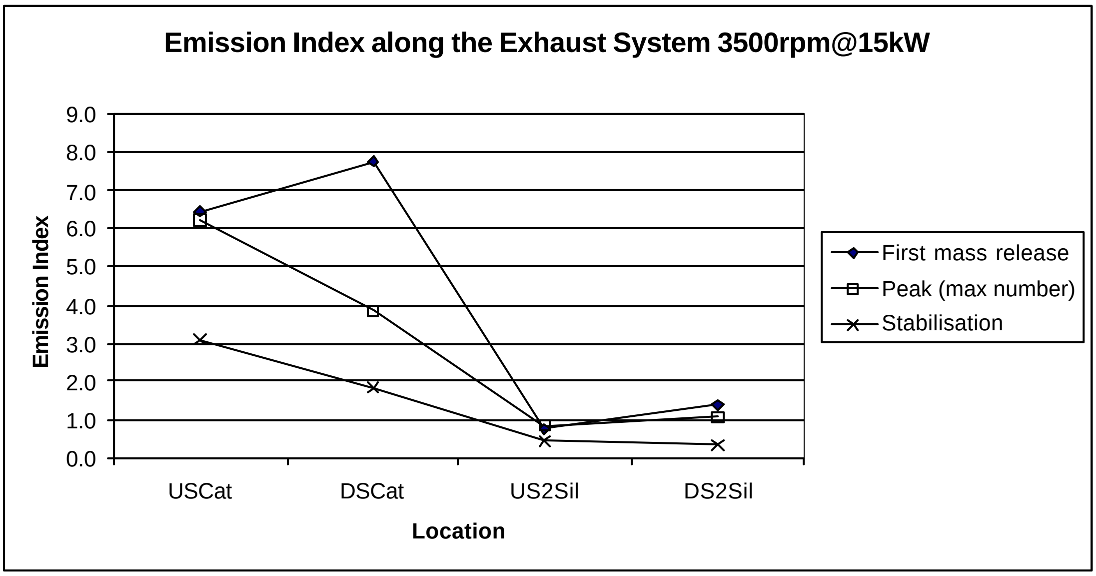


DEPOSITION AND REENTRAINMENT ALONG THE EXHAUST SYSTEM AT THE NEW CONDITIONS TESTED

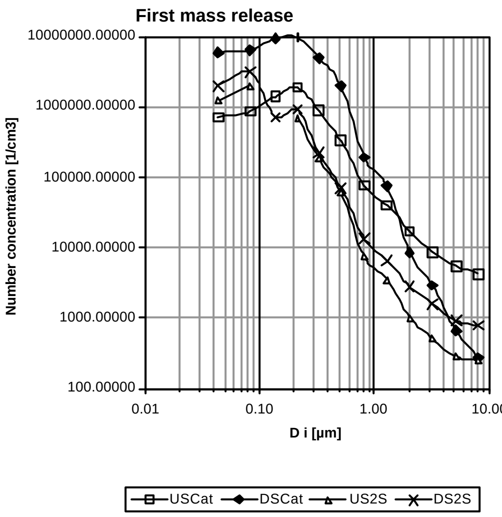
High speed condition

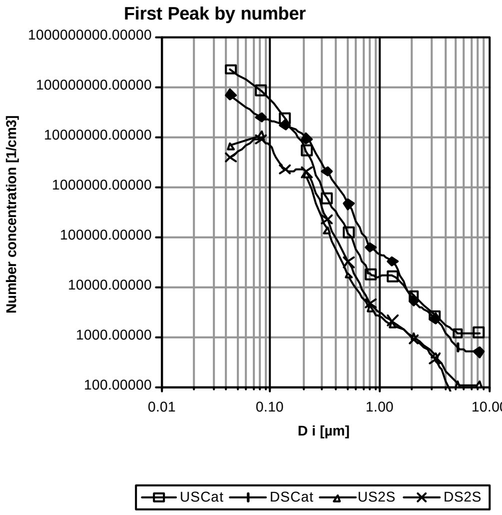
Number concentration increased through the catalyst at the first thirty second mass release at high speed conditions, which would indicate release of particles previously deposited on the catalyst walls. Those released particles were smaller than 2 µm, as shown in the particle size distribution by number and by mass, whereas bigger particles were actually deposited in the catalyst. In the same event, number and mass of particles decreased through the first silencer by deposition at all size ranges, whereas particles bigger than 0.8µm, presumably deposited during preconditioning at idle were released from the second silencer.

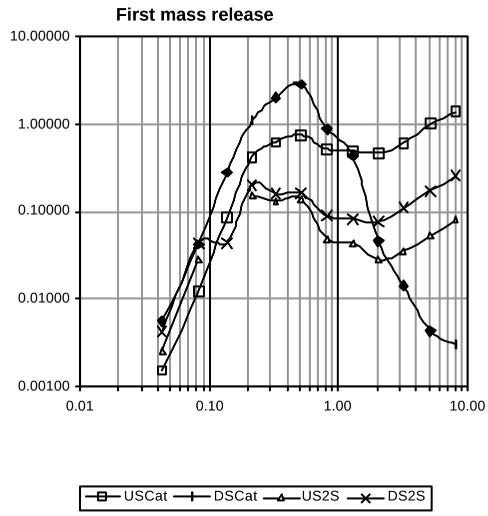


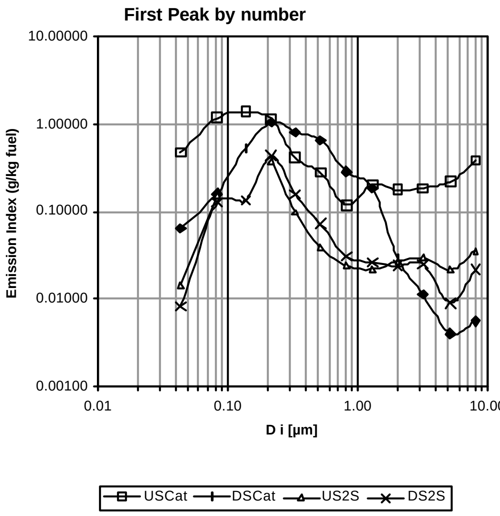


In the peak-by-number event, decrease in particle number and mass occurred through the exhaust system at all size ranges, with some evidence of particle growing. Particles in the middle size range (0.2µm to 1.0µm) showed a slightly different trend from very fine particles and big particles through the catalyst, although the overall effect was decrease in number by deposition (the catalyst had not lit off yet). A slight increase in particle total mass was observed through the second silencer as a result of an increase in the mass of particles bigger than 3µm.







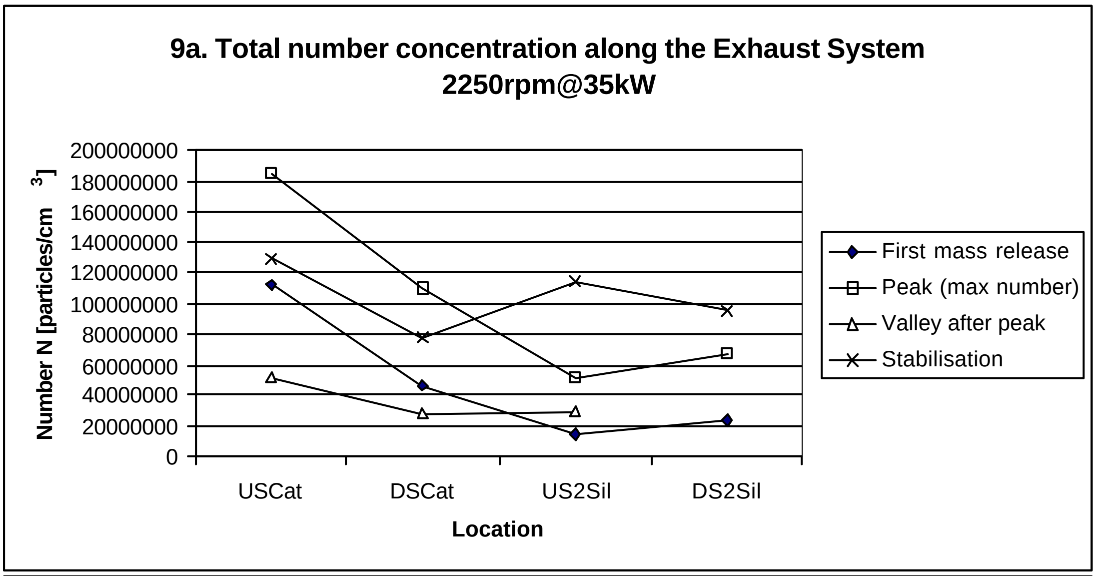


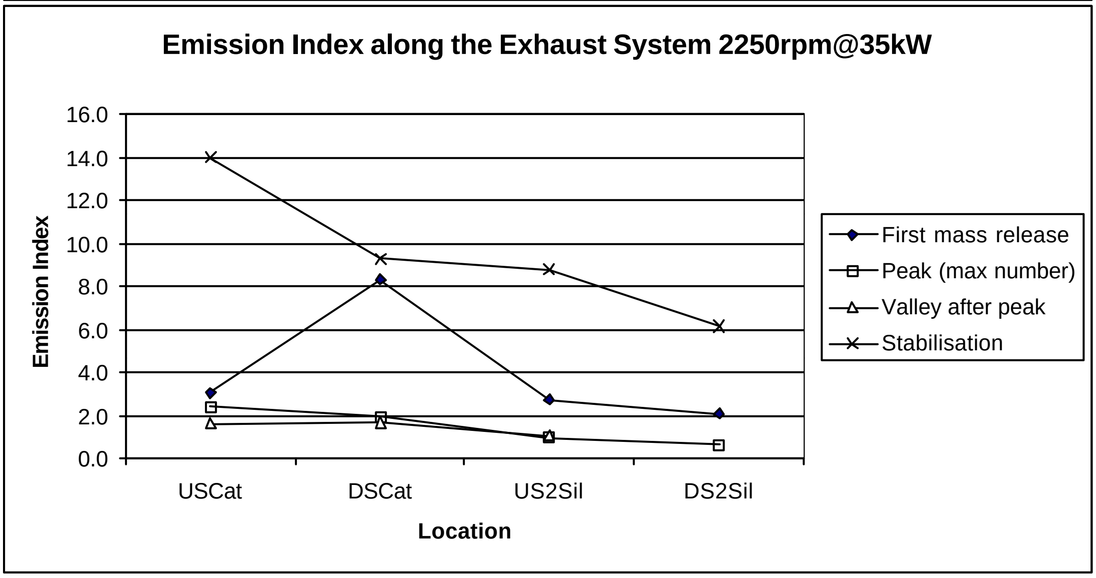
Once the system has reached the stabilisation, decrease in particle numb er and mass was observed through the catalyst and the first silencer. A very slight decrease in number and mass was observed through the second silencer by particle growing.

High load condition

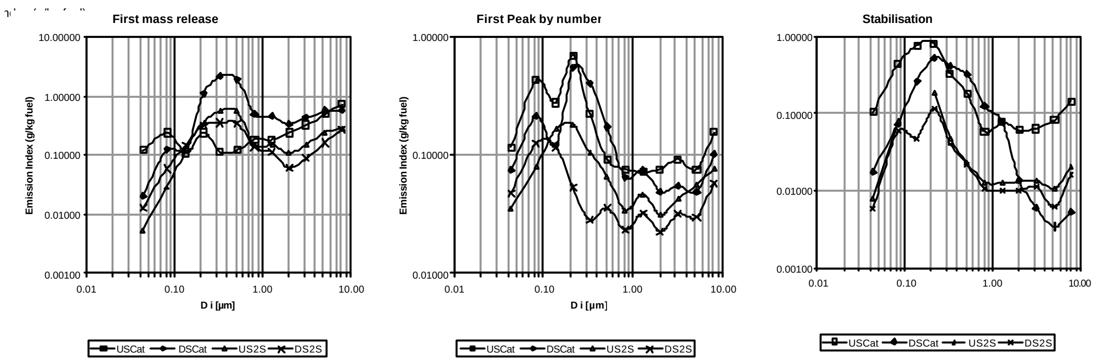
In the first mass release, total number concentration decreased through the catalyst and the first silencer, whereas the mass increased through the catalyst and decreased through the first silencer. The number of particles was reduced only in the finest size range, below 0.10µm and increased for bigger particles, which indicates particle growing and also release of big particles. Through the first silencer, particle number and mass decreased in all size ranges. Through the second silencer, particle number concentration increased, emission index (mass) decreased and the size distributions indicate that gas-to-particle conversion was promoted and the deposition of particles above 1µm occurred.

In the peak-by-number event, number concentration and emission index decreased through both catalyst and first silencer. Emission index decreased slightly through the second silencer despite the number concentration increased through it, owing to an increased number of small particles and the deposition of mid-size and big particles.





In the valley following the peak-by-number event, smaller changes in number concentration and mass were observed through the catalyst and the first silencer, and there was some evidence of particle growing through the catalyst and some deposition of particles through the first silencer.



Opening the EGR valve caused a dramatic increase in the number concentration and emission index at all sampling points. The situation when the exhaust gas seemed to reach an equilibrium was in general a decrease in number concentration and emission index through the catalyst and the silencers, with the exception of an increase in number concentration through the first silencer, presumably caused by gas-to-particle conversion. Bigger particles are emitted when the EGR system starts operating, which is presumably due to growing by condensation and coagulation in the intercooler.

COMMON CHARACTERISTICS IN THE COLD START BEHAVIOUR OF PARTICULATE

1. First mass release showed a trend towards the release of particulate from the catalyst and the second silencer. The particles moving through the exhaust system during this event are mainly in the big size range.

2. In the peak-by-number event particles moving through the exhaust system were very fine and their number and mass was generally reduced when passing through the different components, although some trend towards release from the second silencer was observed. Particle growing through the system was observed.

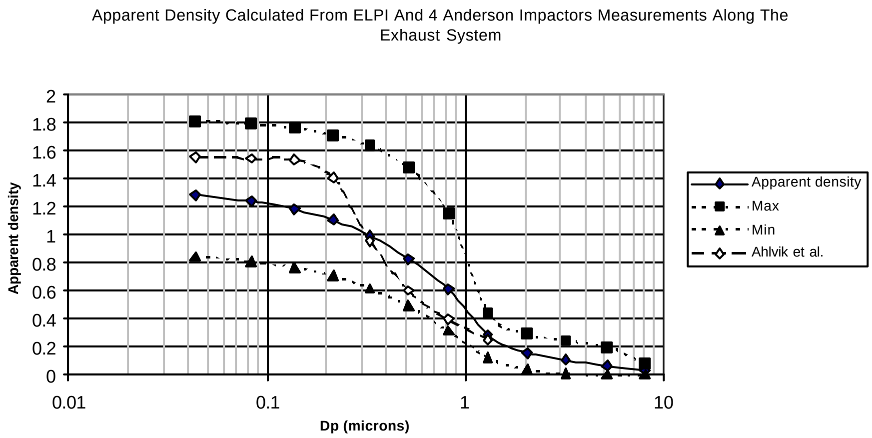
3. The size of particles after the peak-by-number period was around 0.08mm with no significant changes through the different components. Particle number and mass was reduced as the exhaust aerosol passed through the system, presumably by deposition of some medium and big particles and growing of fine particles at the same time.

4. At high load conditions, the EGR valve opening caused an increase in number and mass of particles moving into the exhaust system. Particles leaving the EGR system were in the big size range, owing to particle growth by coagulation and condensation in the intercooler.

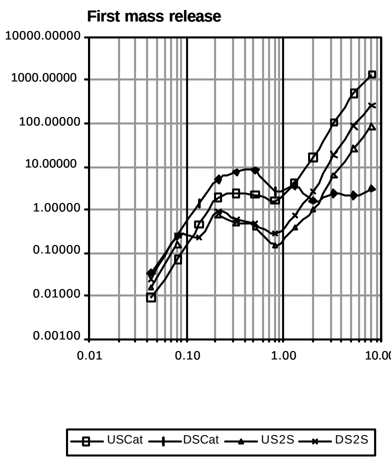
5. Similarly to previous results at lower speed and load conditions, out-of-phase behaviour of the particulate through the different components was observed.

MASS vs. NUMBER: EFFECTIVE DENSITY CALCULATIONS

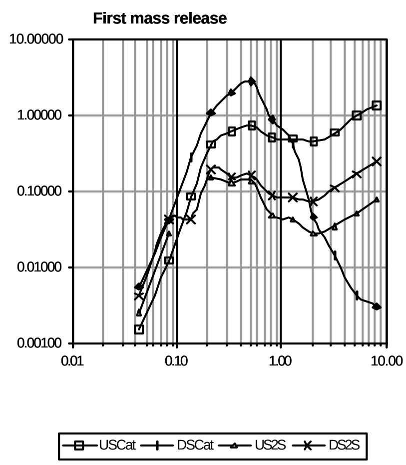
Mass results from the ELPI showed agreement with the gravimetric determination to a certain extent. Problems observed: variability of the measurements, assumptions for the calculation of mass from



Unit density:



“Corrected” density:



number, corrections for particle loss by diffusion and reported data from other authors. Assumption of the particles having unit density shows a very strong influence in these calculations and an attempt to define a function of effective or apparent bulk density has been made.

Previous comparison: SAE 980410, Ahlvik et al. Showed that particle density decreases dramatically with an increase in size, being as low as 0.2 g/cm^3 for particles with a mobility equivalent diameter of 1 µm. We have compared the mass distributions given by the ELPI at each of the four sampling points with the corresponding distributions from Andersen Impactors working simultaneously at all four sampling points at the same steady state conditions and the Emission Index measured gravimetrically. The plot showed the same trend and similar values to those reported by Ahlvik up to 1 µm, and resulted in density values as low as 0.02 g/cm^3 for particles with an aerodynamic diameter of 10 µm. The average apparent density of particles around 0.04µm resulted 1.27 g/cm^3, whereas Ahlvik reported 1.55 g/cm^3 for particles in the same size range.

Once we have applied the density correction to the calculations, the mass-based size distribution changed radically in the range 1 to 10 µm and showed better agreement with the gravimetric determination.