Continuous measurement of density and mass concentration of vehicle exhaust aerosol with MASMO

Ville Niemelä, Mikko Moisio, Pirita Mikkanen, Marko Palonen
Dekati Ltd., Osuusmyllynkatu 13, FIN-33700 Tampere, FINLAND

Abstract

In vehicle exhaust, particulate mass concentration levels approach sensitivity levels of current standard methods. Also the gravimetric mass measurement is time-consuming method and provides no information about time-resolved particle emissions or particle size. Thus there is a need for methods to incorporate the traditional measures with new ones.

Mass is a very strong function of particle size, and therefore the size-selective methods have the best potential for accuracy. However, in order to calculate the particle mass concentration from number distribution additional information about particle density is needed.

A unique technology to continuously measure the particle density has been developed. This method combines information about particle aerodynamic and mobility size measurements into effective density monitoring. Incorporating the information of density with number size distribution of soot particles results in real-time mass concentration.

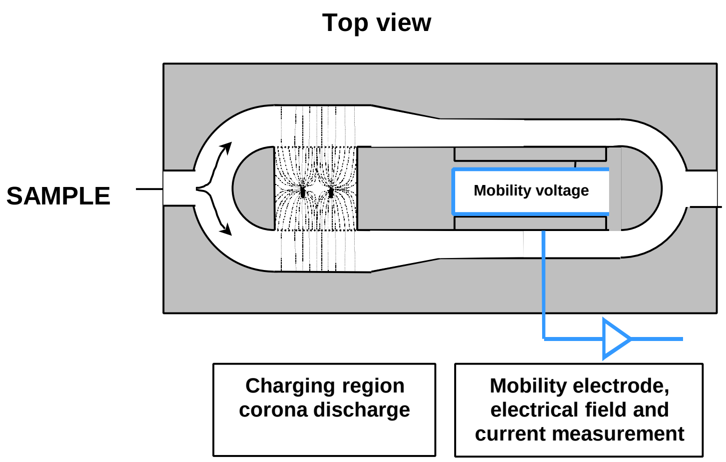
This instrument, called MASMO, has been tested for heavy duty and light duty vehicles. The results are promising, showing a good correlation with measured particle mass concentration.

Instrument description

The operation principle of this new instrument is based on particle charging in a diffusion charger, particle mobility size measurement in a 1st order mobility analyser, size-classification in a low-pressure impactor and electrical detection of charged particles.

The first part of the instrument is a diffusion charger that gives a known, size-dependent positive charge to particles. A corona discharge in a wolfram wire emits ions that due diffusion are collected on the particle surface. In order to minimise the electrical field and therefore the particle losses caused by this high voltage the corona wire is located inside a metal grid, being a triode-type charger.

Charger part contains also a 1st order mobility analyser, an electrical field caused by negative voltage. This field deflects particles carrying a charge after the charging region. The voltage is selected so that particles having adiameter less than 30 nanometers are collected to the electrode, and the current carried by these particles is measured using a sensitive electrometer. The operation principle is seen in picture 1.



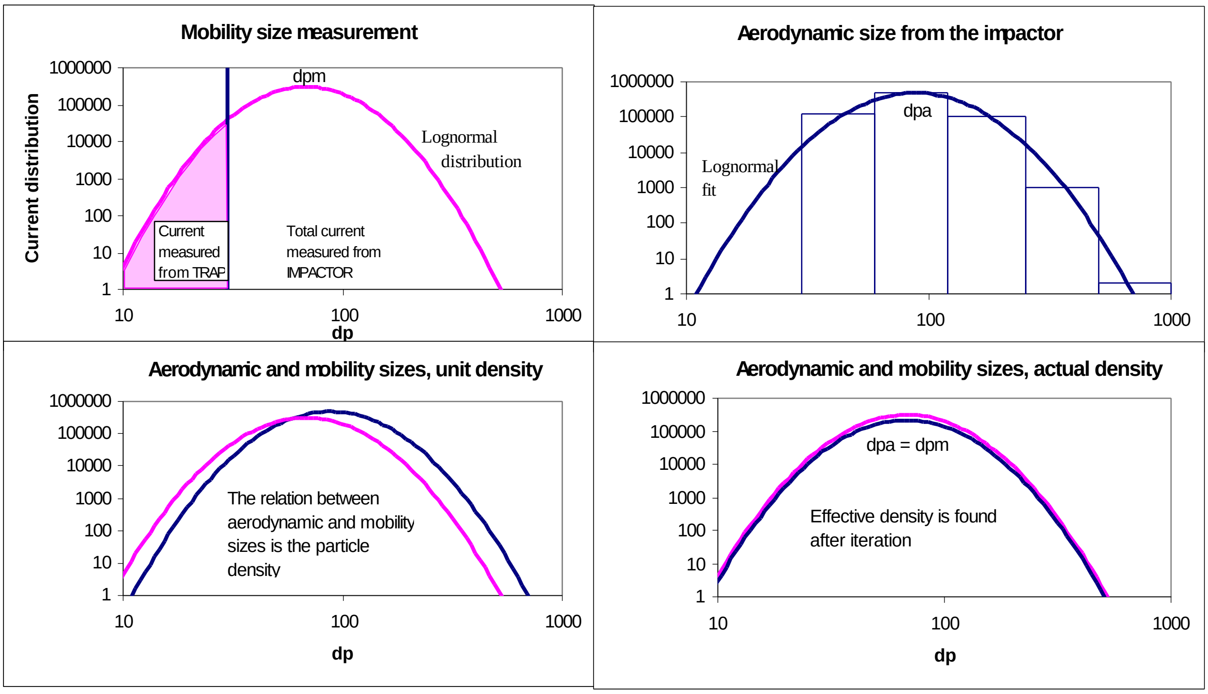
Picture 1: Charger design containing the charging part and the mobility electrode

After the charger the particles enter a 6-stage low-pressure impactor, where the particles are size-classified according to their aerodynamic diameter. The impaction stages are electrically insulated, and each stage is connected to a sensitive electrometer. The current measured from these collection electrodes is proportional to the particle concentration in each size range. The impactor has a new mechanical design with only two operational parts, allowing easy cleaning and handling.

Density measurement

The principle of particle density measurement is to combine particle aerodynamic and mobility size distributions. In this design the aerodynamic particle size is got from the impactor, while the mobility size is calculated using information from both the mobility electrode and the impactor, assuming a lognormal particle size distribution. In vehicle exhaust it is possible to do this assumption, if only accumulation mode (soot particles) are measured.

The density measurement principle is shown in picture 2:

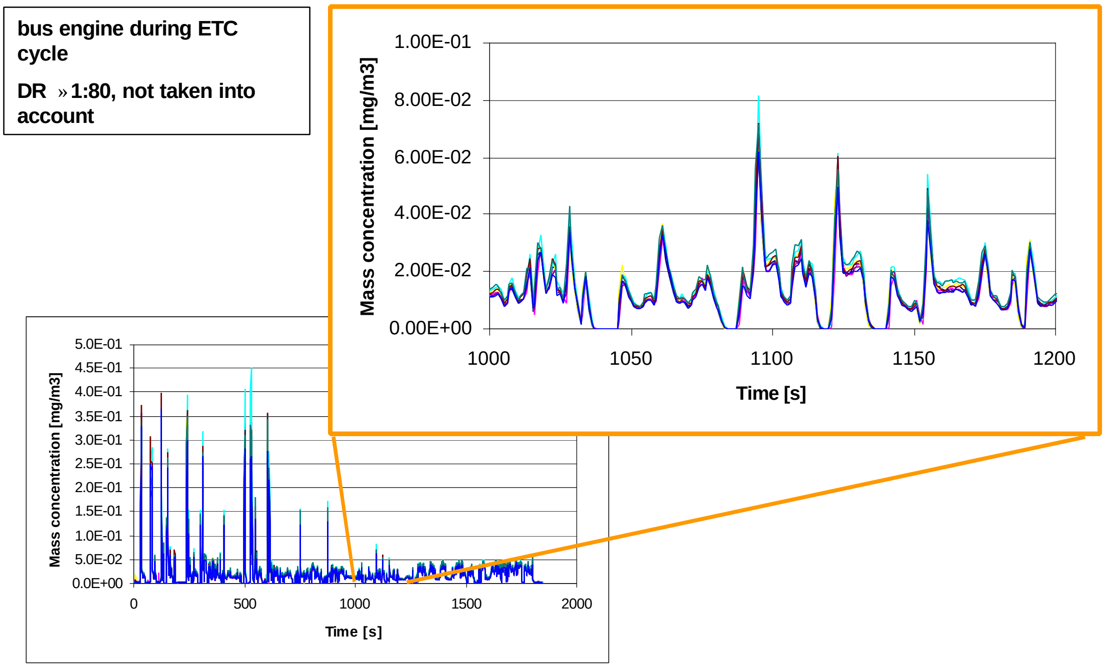


Picture 2: Principle of density measurement

Assuming a lognormal size distribution the mobility size is a calculated from the ratio between mobility electrode current and the total current measured from the impactor. Aerodynamic particle size is measured from the impactor, using a lognormal inversion routine. The difference between aerodynamic and mobility sizes is caused by the particle effective density, and by matching the size distributions the average density value is found.

Measurement results

Measurements were performed using a heavy-duty bus engine equipped with a CRT. The sampling was done directly from the tailpipe, using two ejector diluters, the first one being heated to avoid nucleation of volatile compounds and to get a lognormal, accumulation mode size distribution. Dilution ratio was about 1:8, not taken into account in the results. The drive cycle was European Transient Cycle ETC, repeated 8 times and the particle emission in gravimetric measurement was below EURO 4 regulations. The picture 3 shows the measured mass concentrations:

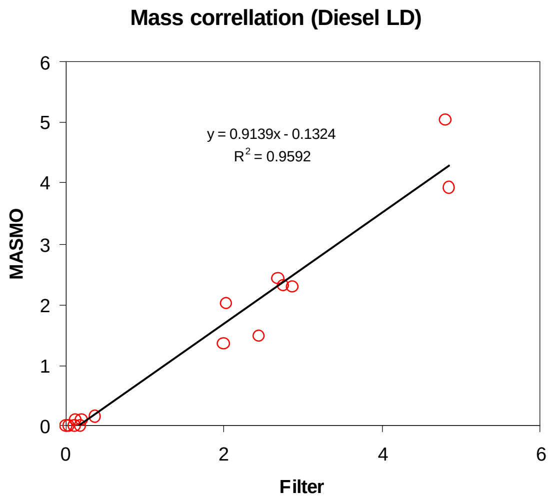


Picture 3: Measured mass concentration during ETC driving cycle.

The repeatability of the measurement was good, and also the sensitivity of the instrum ent was good enough for very low concentration measurements, the detection limit being as low as <1 µg/m^3.

Comparison to gravimetric measurements

Comparison to gravimetric measurement was done using a LD diesel vehicle, and according to picture 4 a good correlation was achieved:



Picture 4: Correlation between gravimetric measurement and MasMo result

Conclutions

A new instrument for on -line vehicle exhaust mass concentration measurements was developed, based on particle charging and electrical detection of charged particles. The method provides excellent sensitivity and fast time responses, while size classification in an impactor provides information about particle size distribution.

In order to get reliable mass concentration results from measu red current values a new, simple method for particle average effective density measurements was introduced, based on comparing the aerodynamic and electrical mobility sizes. By combining the density information with the measured particle sized distribution it is possible to calculate the total particle mass concentration that is comparable with the gravimetric mass measurement.

References:

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Maricq, M., Chase, R.E. & Xu, N. 2001. A comparison of tailpipe, dilution tunnel and wind tunnel data in measuring motor vehicle PM. Journal of the Air & Waste Management Association (1995) 51 (2001) 11:1529-1537

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Ville Niemelä
Dekati Ltd.

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Contents

Goal

- ❖ On-line particle mass measurement for vehicle exhaust
- ❖ Information about particle size
- ❖ Sensitive enough for future emission levels and regulations
- ❖ Results comparable to gravimetric measurements

MASMO design

- Technologies
  - Low loss diffusion charging (triode)
  - Low loss electrical cascade impactor (30-2500nm)
  - Average effective density measurement for mass concentration measurement. Principle from ELPI / SMPS comparisons
- Assumptions
  - Lognormal particle size distribution
  - No nucleation, soot mode only
- Result
  - Real time mass concentration, comparable to gravimetric measurements
  - Median particle diameter + GSD for soot mode

Mass monitor concept

Triode charger

- Low losses
- Easy service
- Low field charging

Electrical classification

- Average particle density
- Below 30nm size

Impactor

- Sintered stages
- Low loss area
- Collection plate measurement
- Small volume
- Easy to clean & service
- All stages removable together

☺ Low losses

☺ User frienly

☺ Mass concentration via density measurement

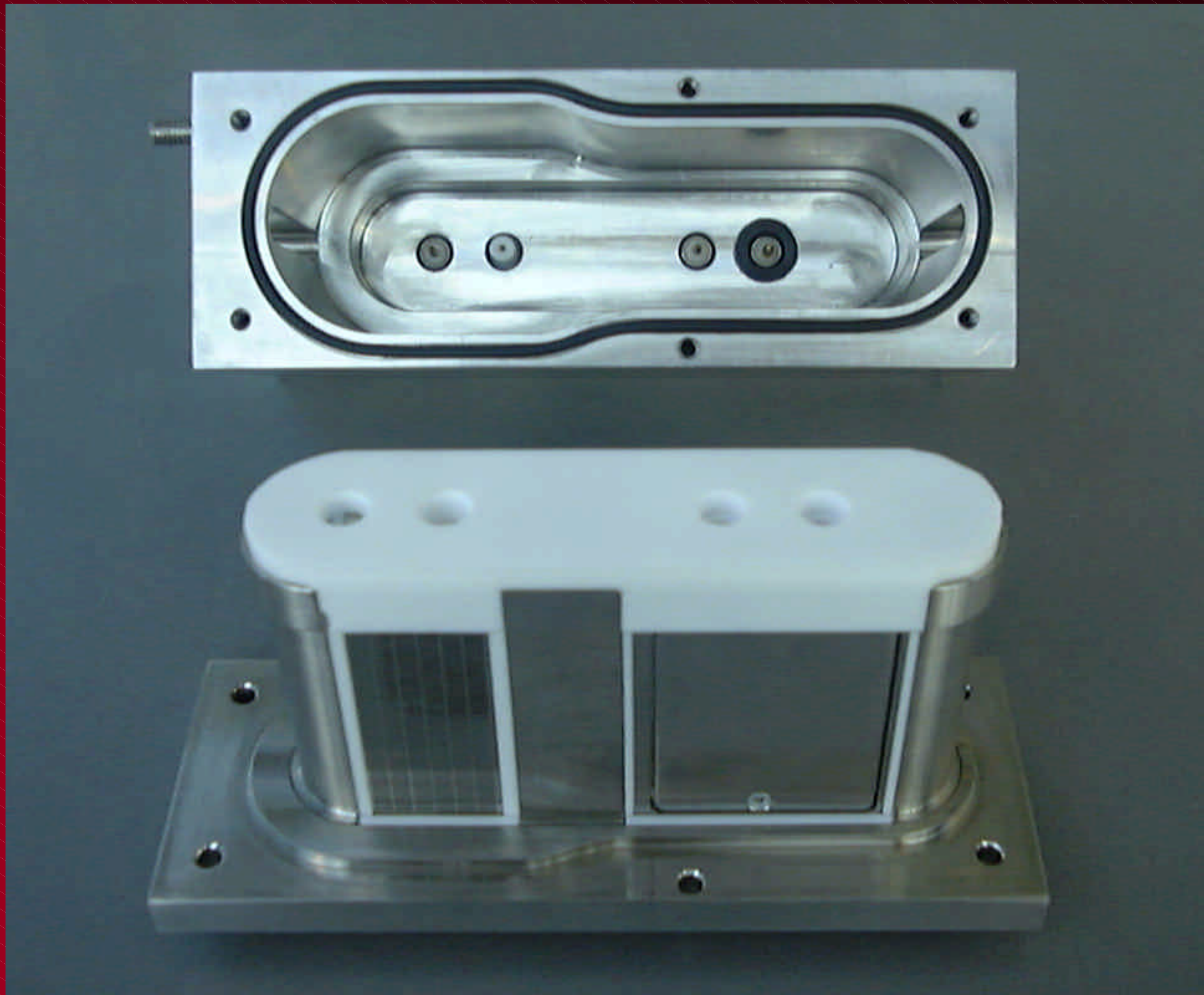
☺ Intergrated to test cell systems

☺ Online data processing/raporting

Detector

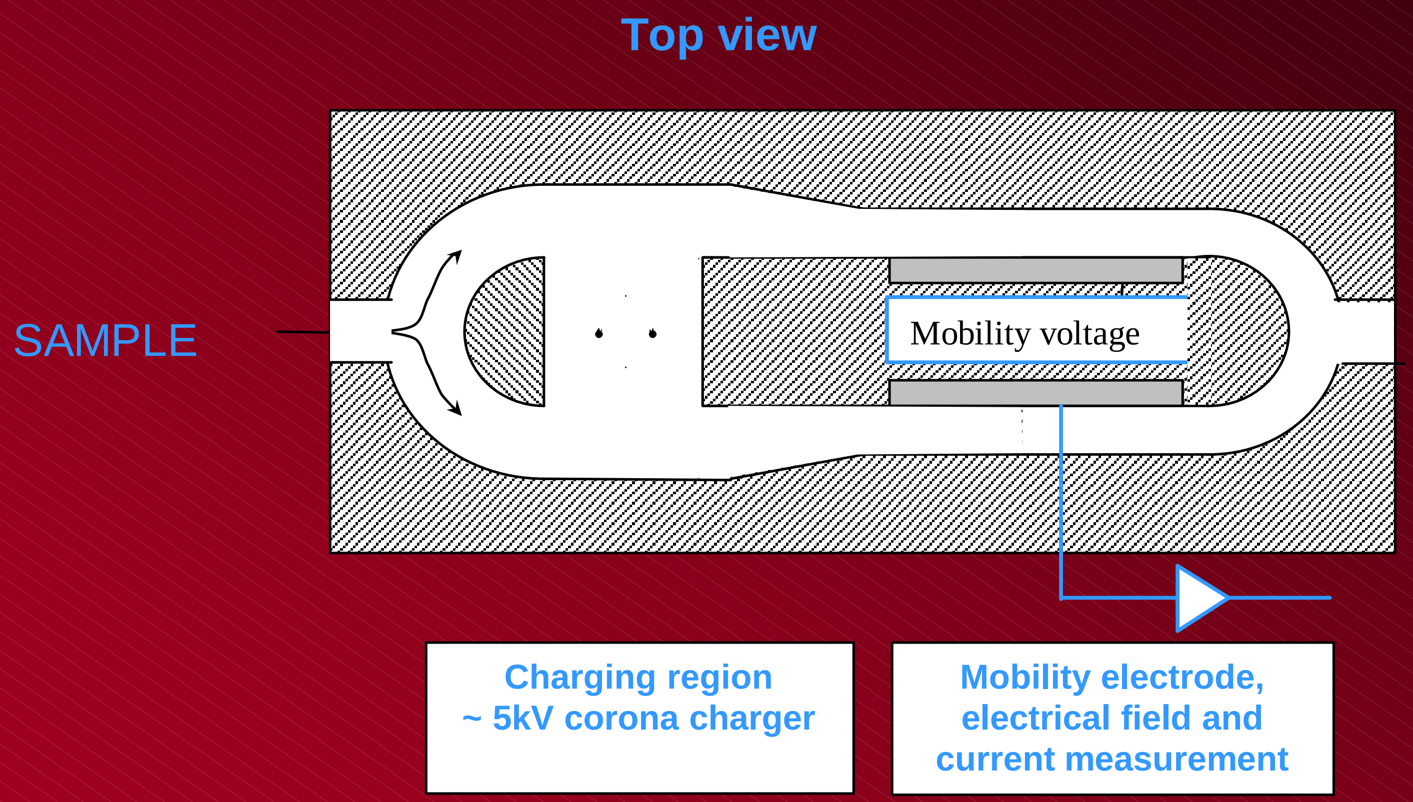
- 6-stage impactor for size-classification, lognormal inversion routine
- New impactor construction –”rod”
  - only two operational parts
  - collection rods removed with one operation
  - quick to clean and replace

Charger construction



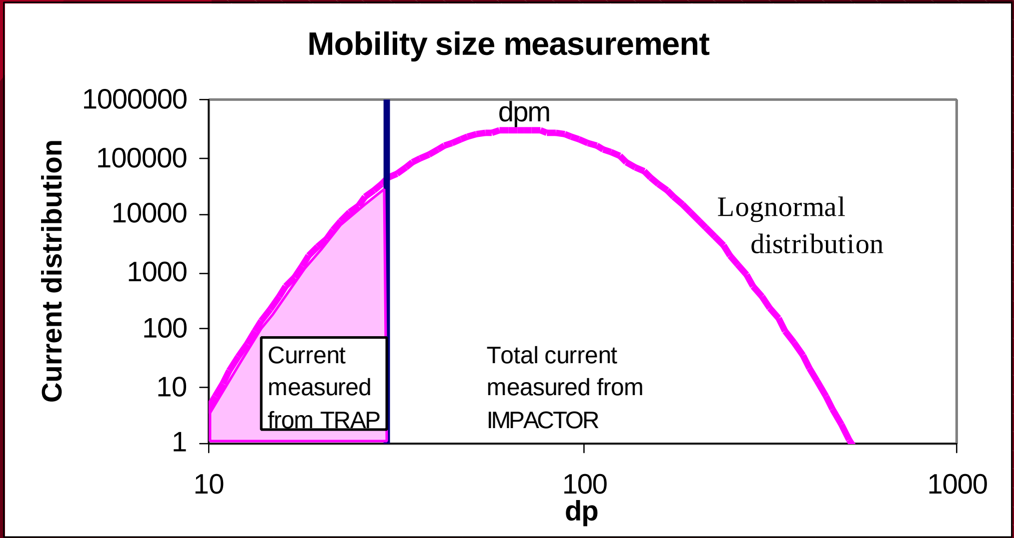
Charger design

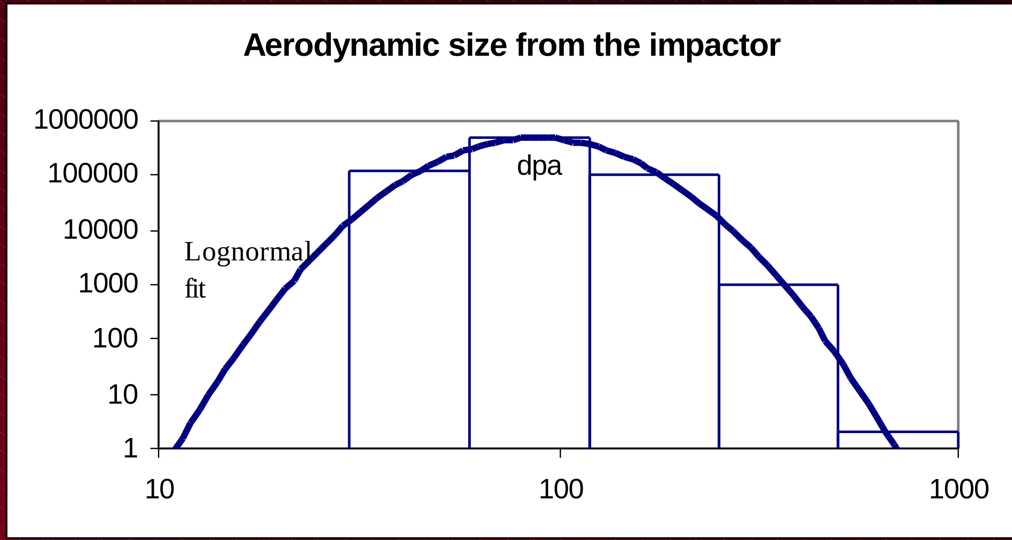
- Triode type charger, integrated mobility electrode
- Excactly known charge to particles

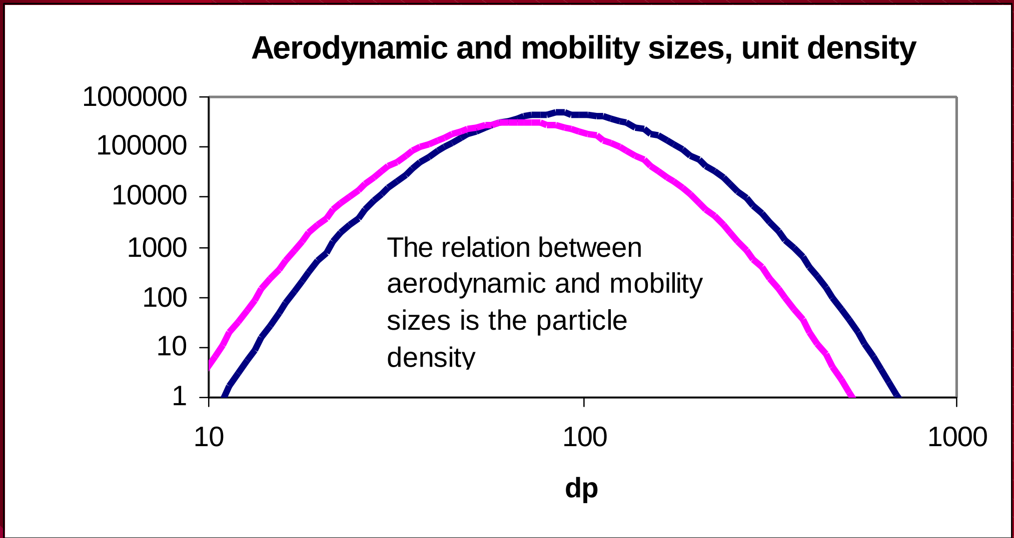


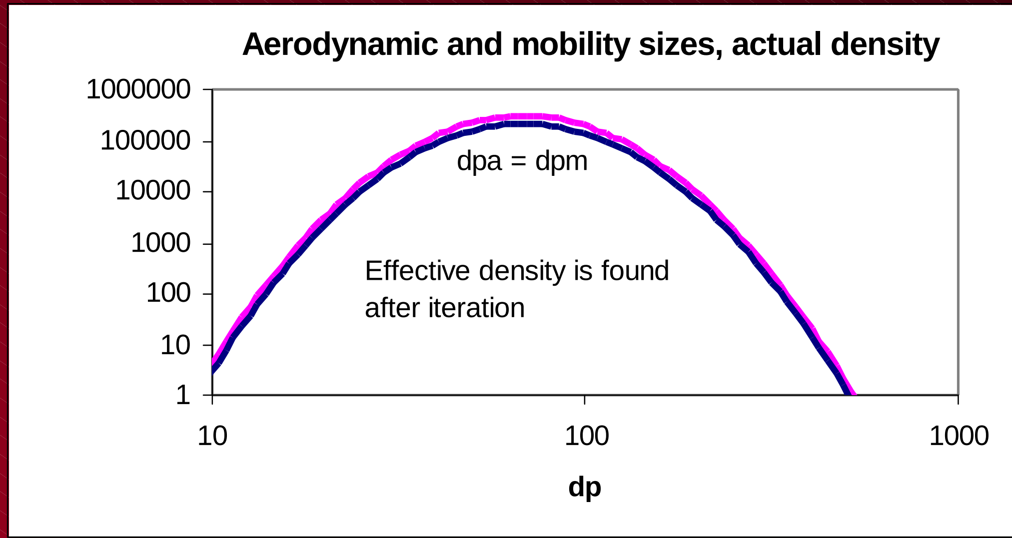
Principle of density measurement

Comparison between aerodynamic and mobility sizes

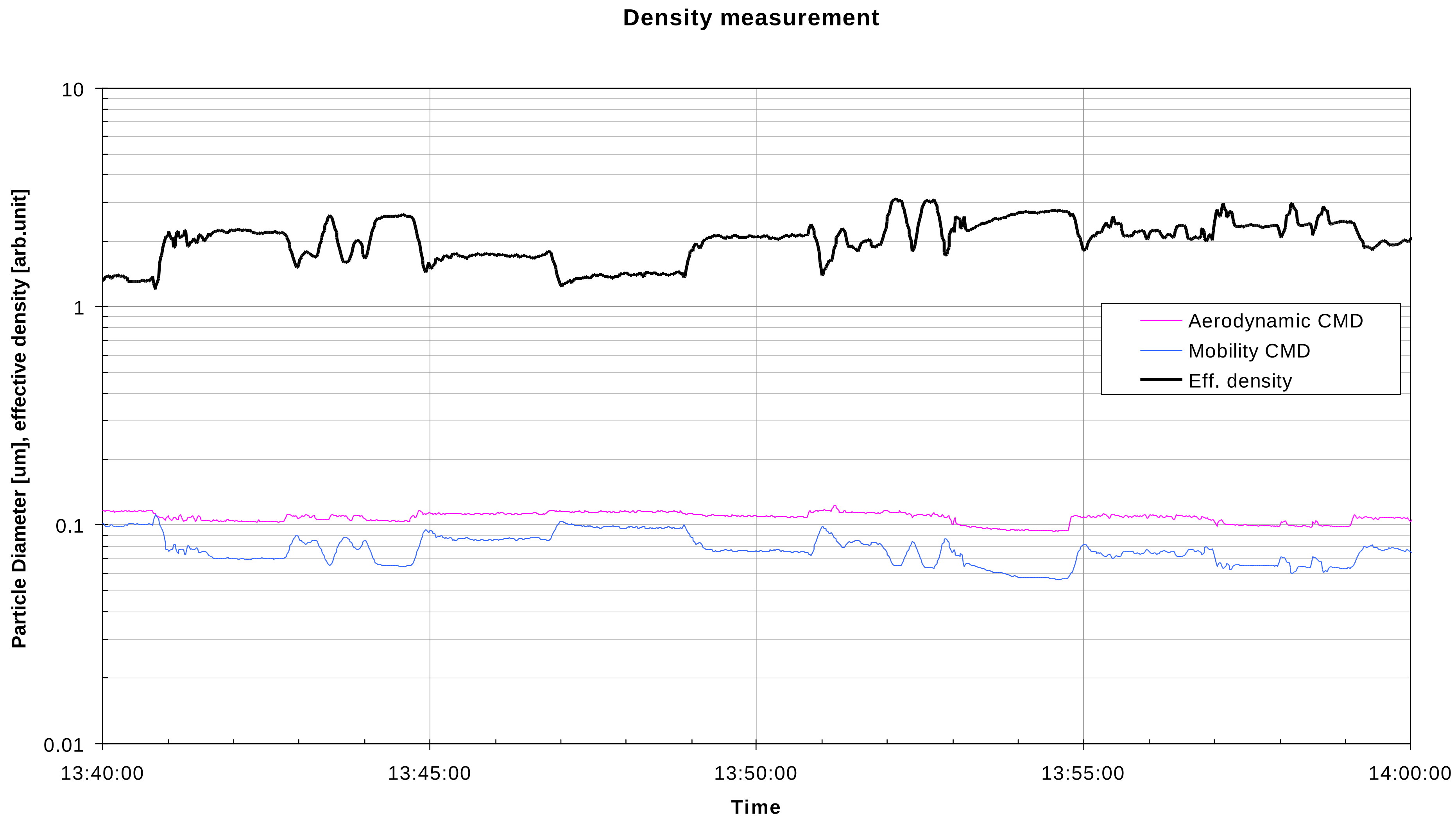








Density measurement

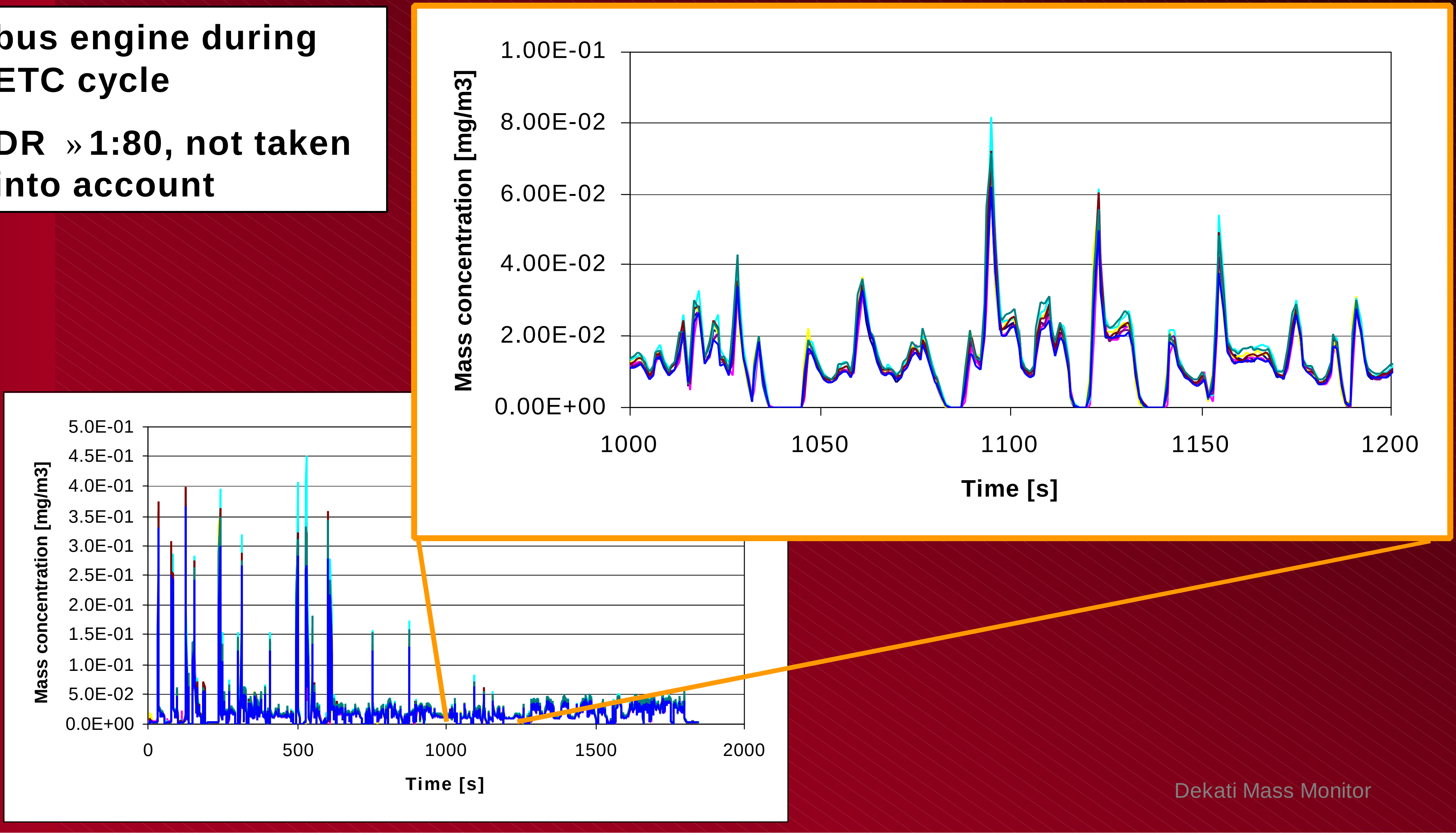


HD engine, transient tests (ETC)

- ❖ 8 repeations, concentration below EURO 4 regulations

bus engine during ETC cycle

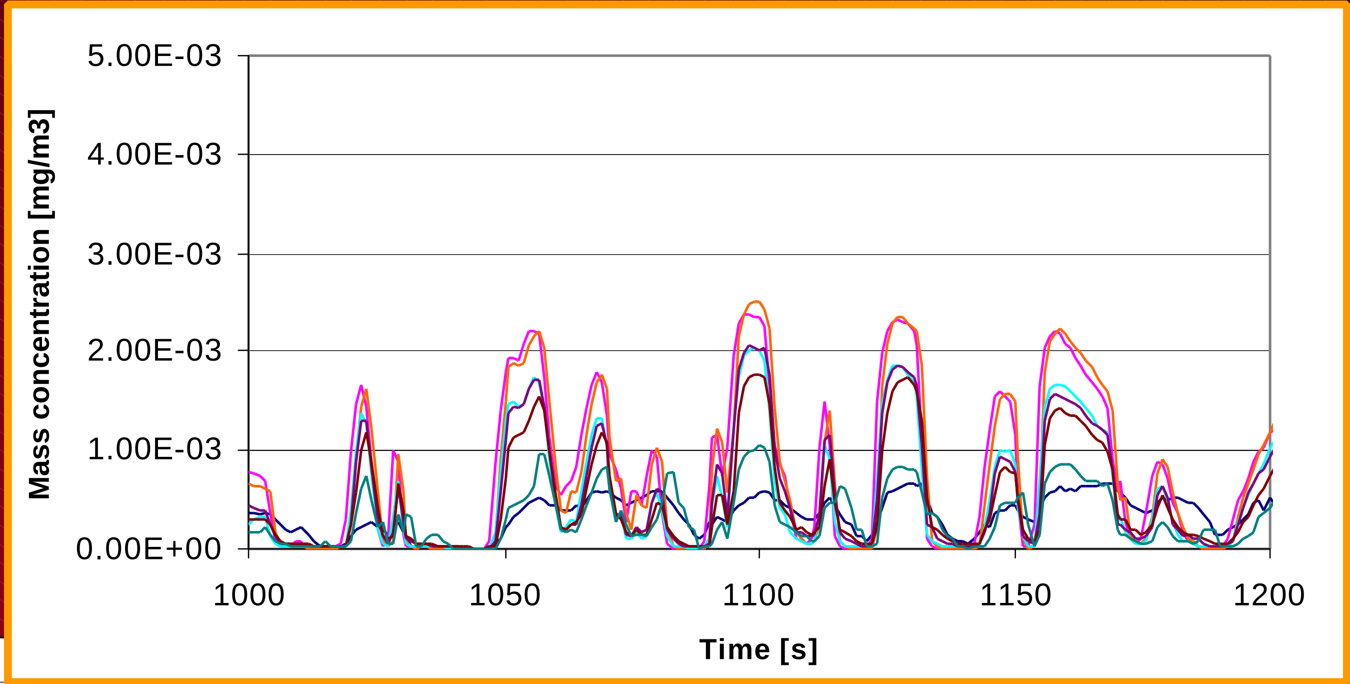
DR » 1:80, not taken into account

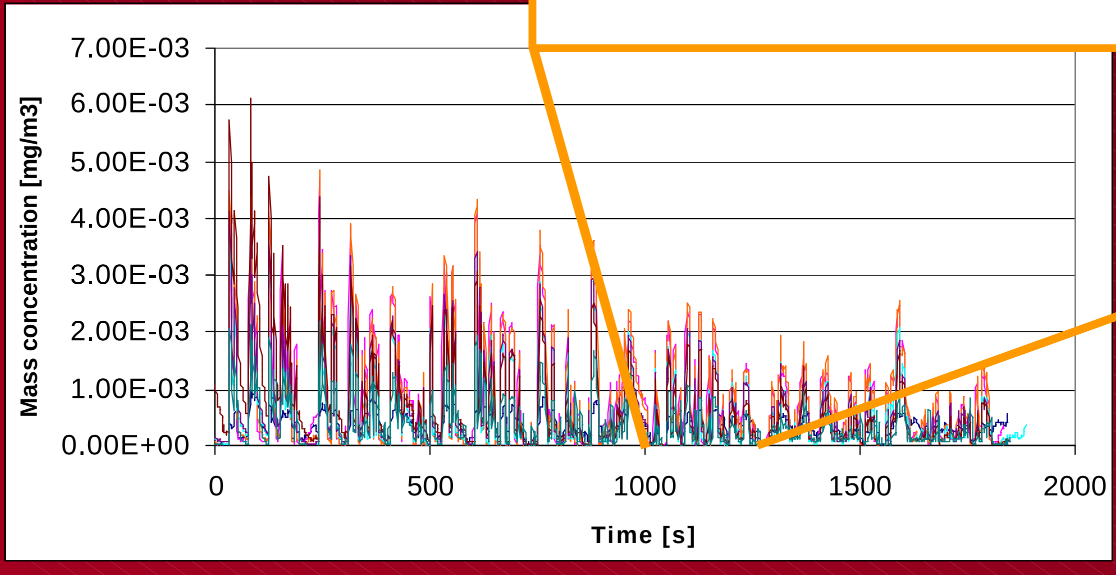


HD engine + CRT, transient tests (ETC)

8 repeations, bus engine with CRT

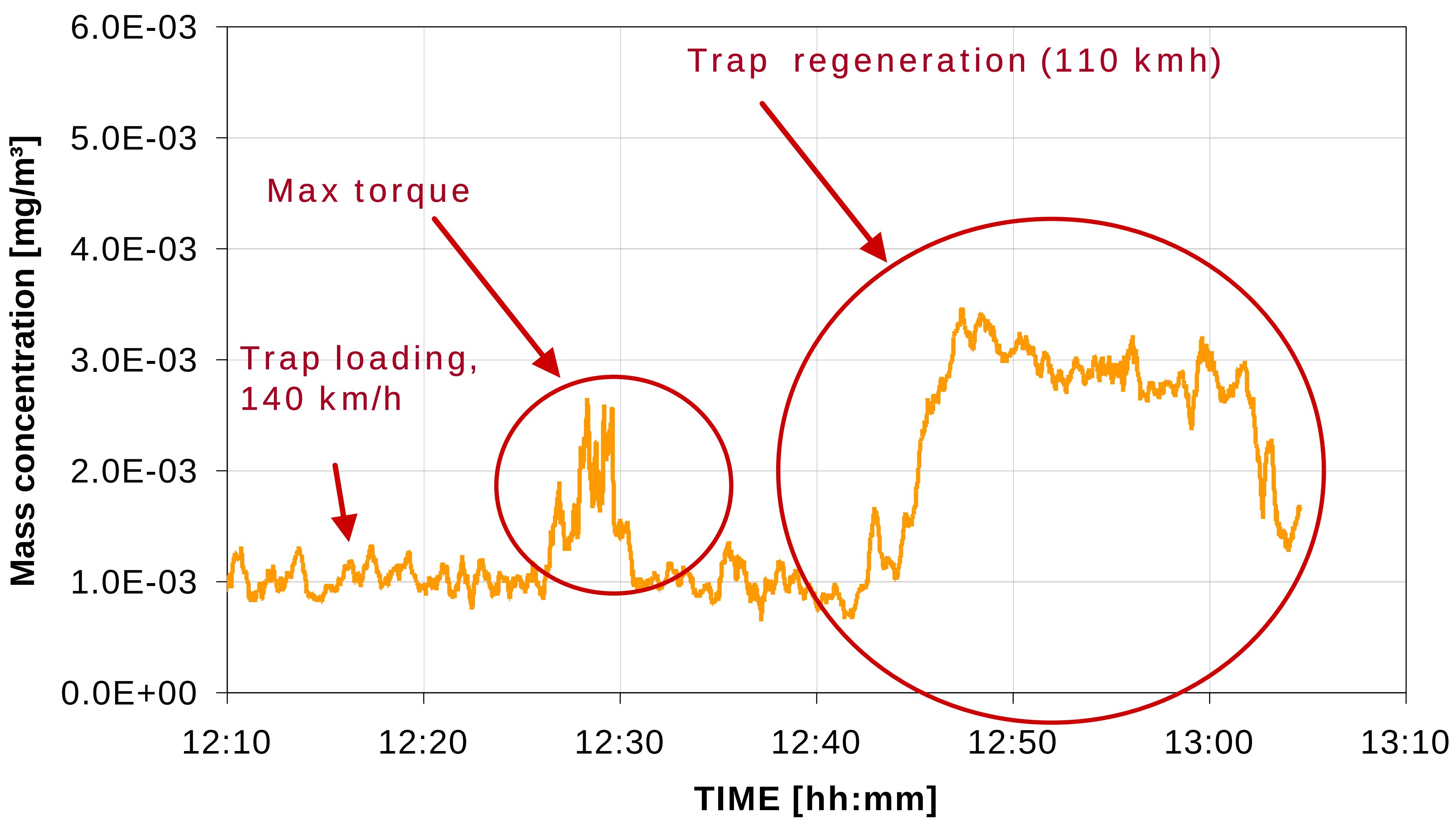
DR » 1:10, not taken into account



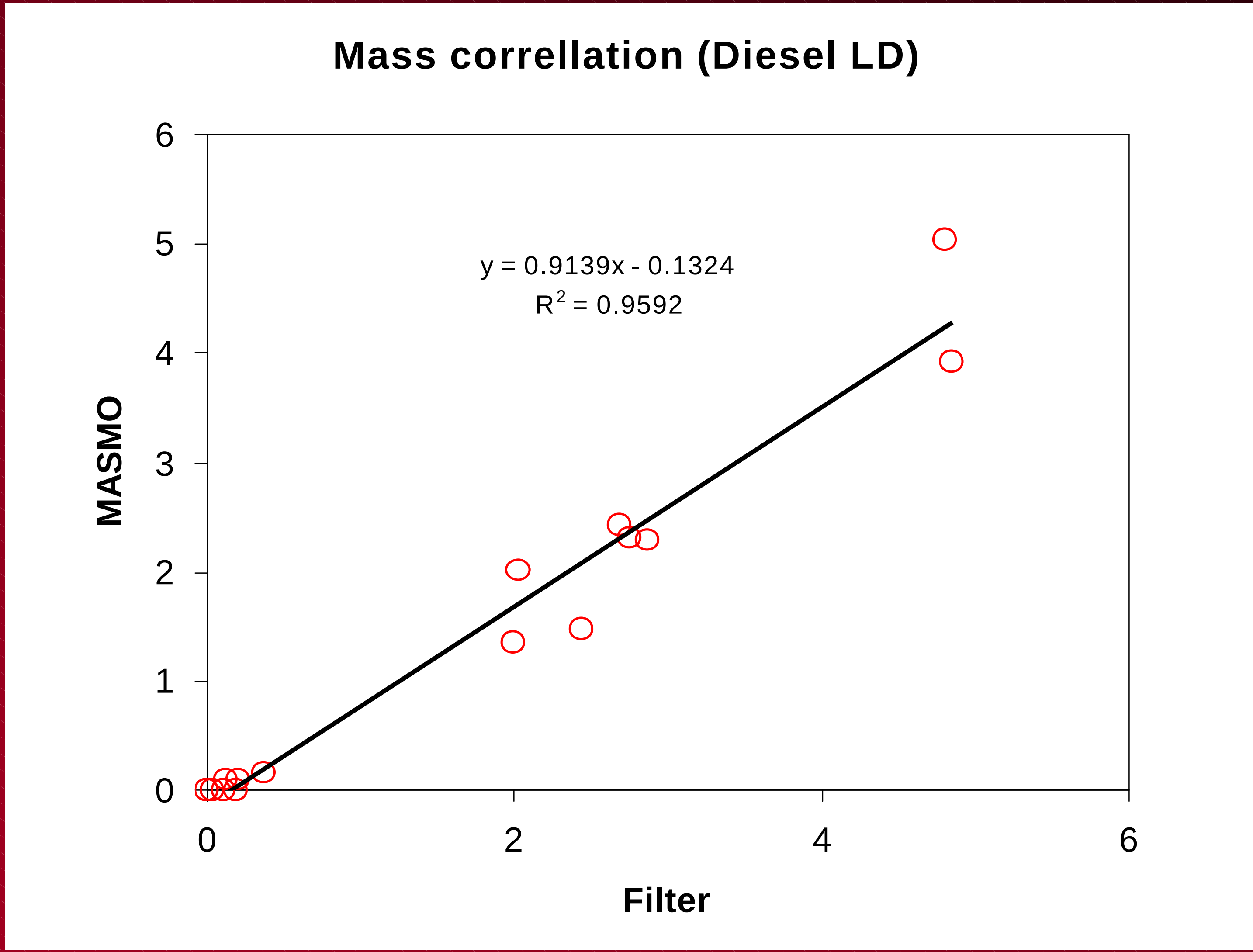


LD trap regeneration, low emission

- Citroen C5 HDI + trap, DR=65 (not taken into account)



Gravimetric filter comparison



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Conclusions

- A new design for electrical impactor
- Technology to measure the average particle density
- A new, very sensitive real-time instrument for vehicle particulate mass emission measurements
- Results comparable to gravimetric measurements