REAL-TIME MEASUREMENT OF DIESEL TRAP PM REMOVAL EFFICIENCY

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Introduction

Determination of diesel particle filter (DPF) or other aftertreatment device PM removal efficiency is commonly done with a standard sampling system such as CVS tunnel and gravimetrical PM mass measurement. However, when the reduction of particle mass is measured with this method there are several uncertainties with new, highly efficient diesel traps. In this paper we discuss about these issues and introduce an alternative system for a more sensitive and better-controlled measurement.

Issues and problems with CVS tunnel and gravimetric measurement

Concentrations downstream modern, high-efficiency Diesel Particle Filters are very low, setting high requirements for gravimetric measurements. The microbalance, weighing rooms and sampling systems have to be state-of-the-art in order to get as repeatable results as possible, since the collected mass can be as low as just few micrograms.

Secondly, filter papers collect all particles with high efficiency, but they are also collecting some gas-phase material [Chase et al]. With conventional diesels this artefact is almost negligible since solid particles dominate the mass, but downstream DPF there are no longer solid particles, and the gas-phase material might affects the results, depending on the filter material.

Thirdly, dilution parameters have a significant effect on the measured PM concentrations. Even when the amount of solid particles is constant the volatile material can condensate, evaporate and nucleate depending on the dilution ratios and temperature profiles. In a CVS tunnel these parameters are not constant and controlled only roughly [Lamminen et al.]. This is especially an issue in post-DPF measurements where basically all particles are volatile. On the other hand, oxidation catalysts remove mainly volatile PM, therefore if only solid particles are detected the efficiency measurement reports very poor performance while total PM measurement gives much higher efficiencies.

Finally, Diesel Particle Filters or Catalysts affect to the engine back pressure, and this has an effect on the engine operation. Normally when engine out emission is measured the aftertreatment device is removed and the backpressure is controlled with e.g. a valve in the tailpipe. However, in actual situation the delta P is not constant, and it depends on the filter loading and engine speed. Furthermore, CVS tunnel setup does not allow DPF regeneration studies.

Methods

Electrical detection of particles is more sensitive method for particle detection than gravimetric measurement, and tailpipe sampling allows better control over the dilution parameters. In this work a two-part system was developed for well-controlled aftertreatment studies, consisting of a tailpipe sampling device and real-time PM mass measurement instrument.

Dekati Mass Monitor DMM is based on particle charging, inertial and mobility size classification and electrical detection of charged particles, and it provides better sensitivity and time resolution than traditional PM measurements [Mohr et al.]. Several international studies have proved that the result is comparable to gravimetric measurements [Lehmann et al.].

Dekati Fine Particle Sampler FPS is a sampling system for tailpipe particle measurements. Dilution parameters are controlled, including dilution ratio control in the range of 1:15-1:200, temperature control (10-300°C) and real-time dilution ratio determination. It can take the sample from high overpressures in a controlled way.

Together these two instruments are a transportable measurement system for diesel and gasoline PM measurements. The system can take the sample from upstream or downstream DPF, allowing measurement of the DPF PM removal efficiency and DPF regeneration studies. Its sensitivity goes down to a level of few micrograms / m3, and all the data is recorded in second-by-second basis. Result is also available via analog output signal, allowing its integration to a test cell equipment.

Results:

Table 1 shows data measured downstream DPF and with DPF bypass so that EURO IV PM criteria is met. It is clearly seen that at low emission level the used TX-40 filter shows more mass than the real-time Dekati Mass Monitor DMM. Therefore the DPF efficiency measured with the DMM is much higher than when measured with a gravimetric filter and CVS tunnel (efficiencies 99.8% and 85.6%). However, number-based DPF efficiency measurements in the same study showed efficiencies higher than 99.9%. The main reason for the difference is the filter artefact, where the filter type plays important role. TX-40 used in Europe has higher tendency to collect gas-phase material than e.g Teflo -filters used for US2007 measurements.

		Tailpipe concentrations [mg/Nm3]:	After 1:10 dilution [mg/Nm3]:	Collected mass [ug] (70 lpm, 30 min)
Post-DPF	Gravimetry	0.31	0.031	65.1
	DMM	0.005	0.0005	1.05
EURO IV-Level engine	Gravimetry	2.16	0.216	453.6
	DMM	2.56	0.256	537.6

Table 1: Measured mass concentrations from the DMM and gravimetric measurement, and estimated amount of particles collected to a filter paper in similar conditions [Mohr et al.]

FPS can be connected both upstream and downstream diesel aftertreatment device, and it allows well-controlled method for PM removal efficiency measurements, also during the regeneration process. Measurements have been performed from up to 1000 mbar overpressures.

Conclusions:

The following conclusions can be drawn from this study:

- When a DPF PM removal efficiency is reported it is important to clarify the used measurement method since different systems can result to a different performance.
- Electrical detection of particles offers higher sensitivity for PM measurements than gravimetric PM mass determination and without gas-phase material interference
- Tailpipe sampling offers better control over the dilution parameters than a CVS tunnel

References:

Chase, R., Duszkiewicz, G., Richert, J., Lewis, D., Maricq, M., Xu, N. (2004): PM measurement artefact: organic vapour deposition on different filter media. SAE Technical Paper Series 2004-01-0967

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Lehmann, U., Niemelä, V., Mohr, M. (2004): New Method for Time-Resolved Diesel Engine Exhaust Particle Mass Measurement. Environmental Science and Technology, vol 38(21), pp 5704 - 5711.

Real-Time Measurement of Diesel Trap PM Removal Efficiency

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AEROSOL INSTRUMENTS

Contents

Introduction

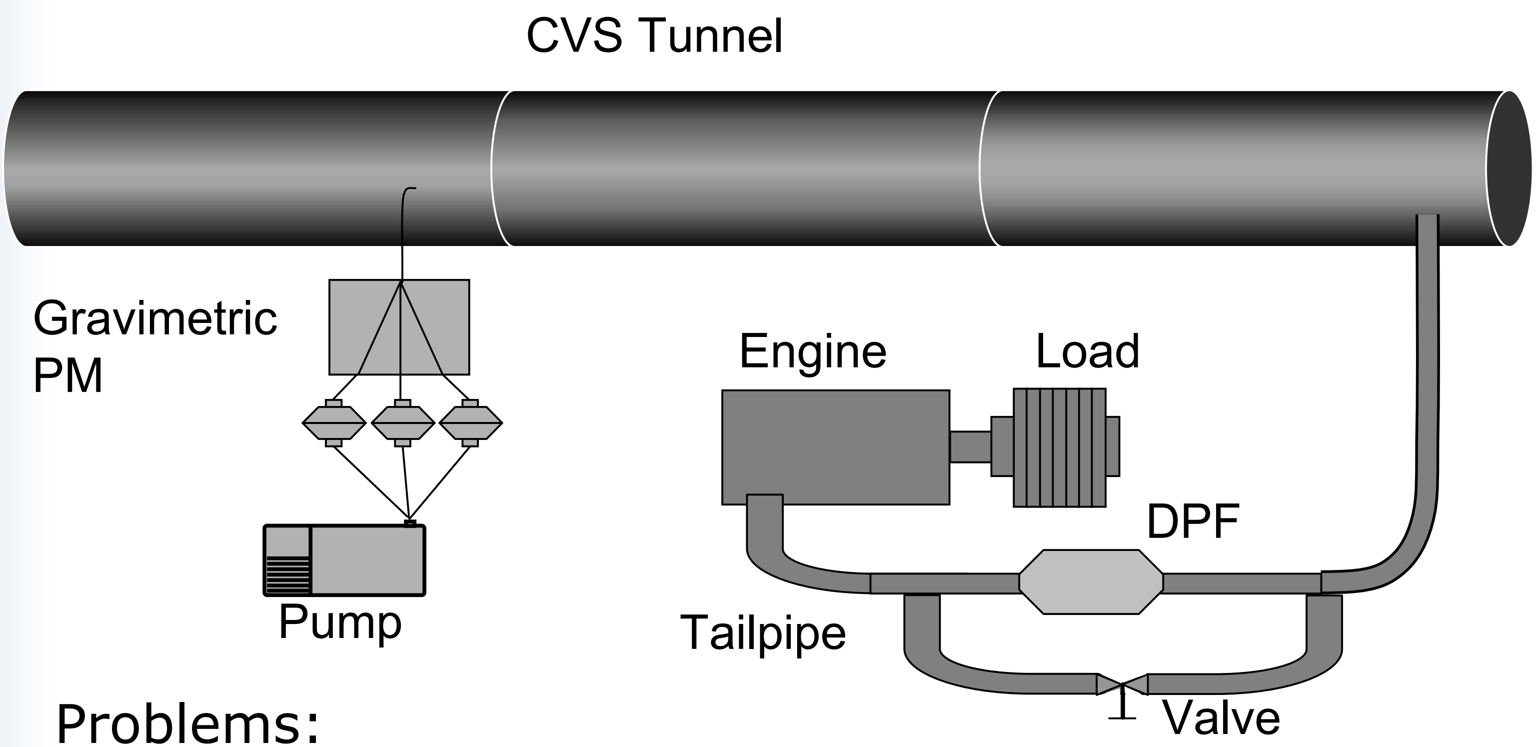
- Diesel Particle Filter (DPF) is very efficient in removing solid particles
  - Downstream DPF there are only volatile particles
- Oxidation catalysts remove volatile PM, and the efficiency is much lower
  - After Oxidation catalyst PM consists mostly of solid material (dry soot)
- Efficiency is the ratio between upstream and downstream concentrations, but the comparison can be difficult due to volatile material

Objective

To develop a measurement system for aftertreatment studies

- Controlled dilution pre- and post-DPF
- Sensitive measurement
- Wide dynamic range
- Real-time data, also during the regeneration

CVS tunnel measurement



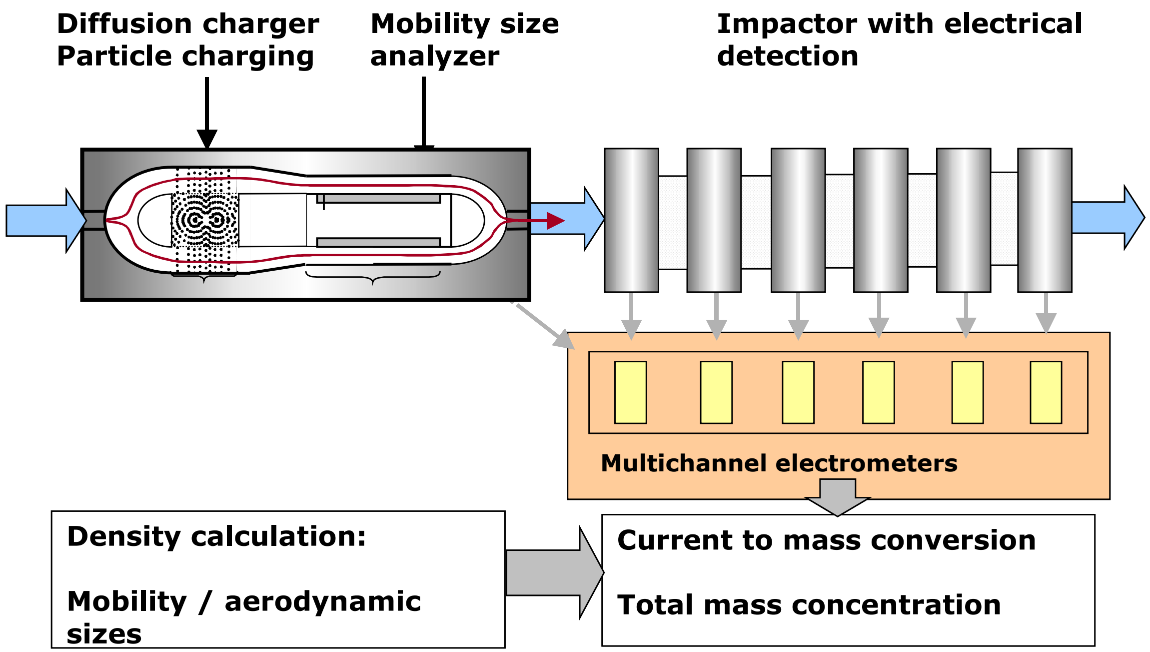
Problems:

- Sensitivity
- Filter artefact
- History effects
- Volatile material treatment
- Engine backpressure control

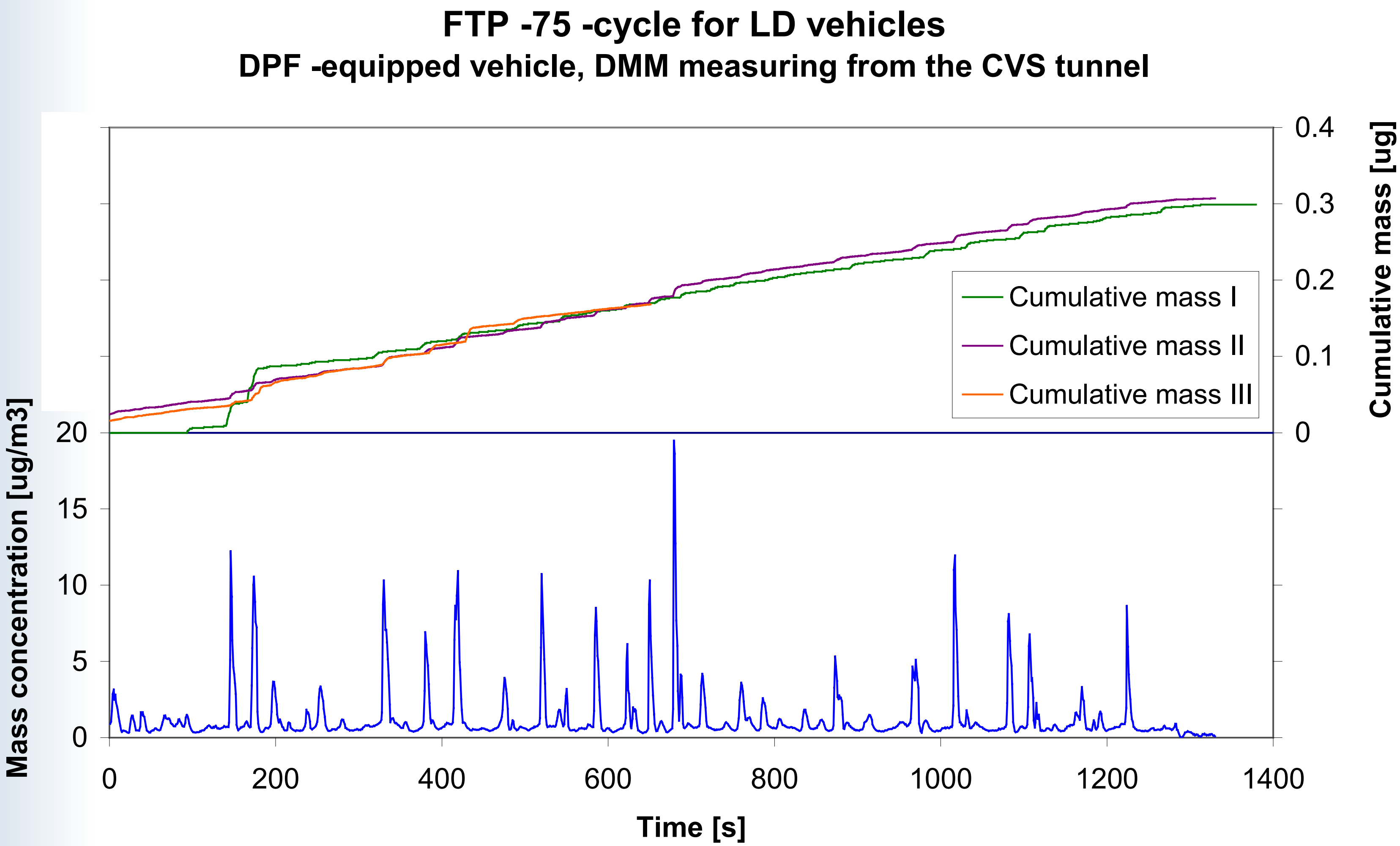
Solution 1: Electrical, real-time PM measurement

- Counting or electrical detection of particles is more sensitive method for particle detection than gravimetric measurement

- Dekati Mass Monitor DMM is based on particle charging, inertial and mobility size classification and electrical detection of charged particles, and it provides better sensitivity and time resolution than traditional PM measurements

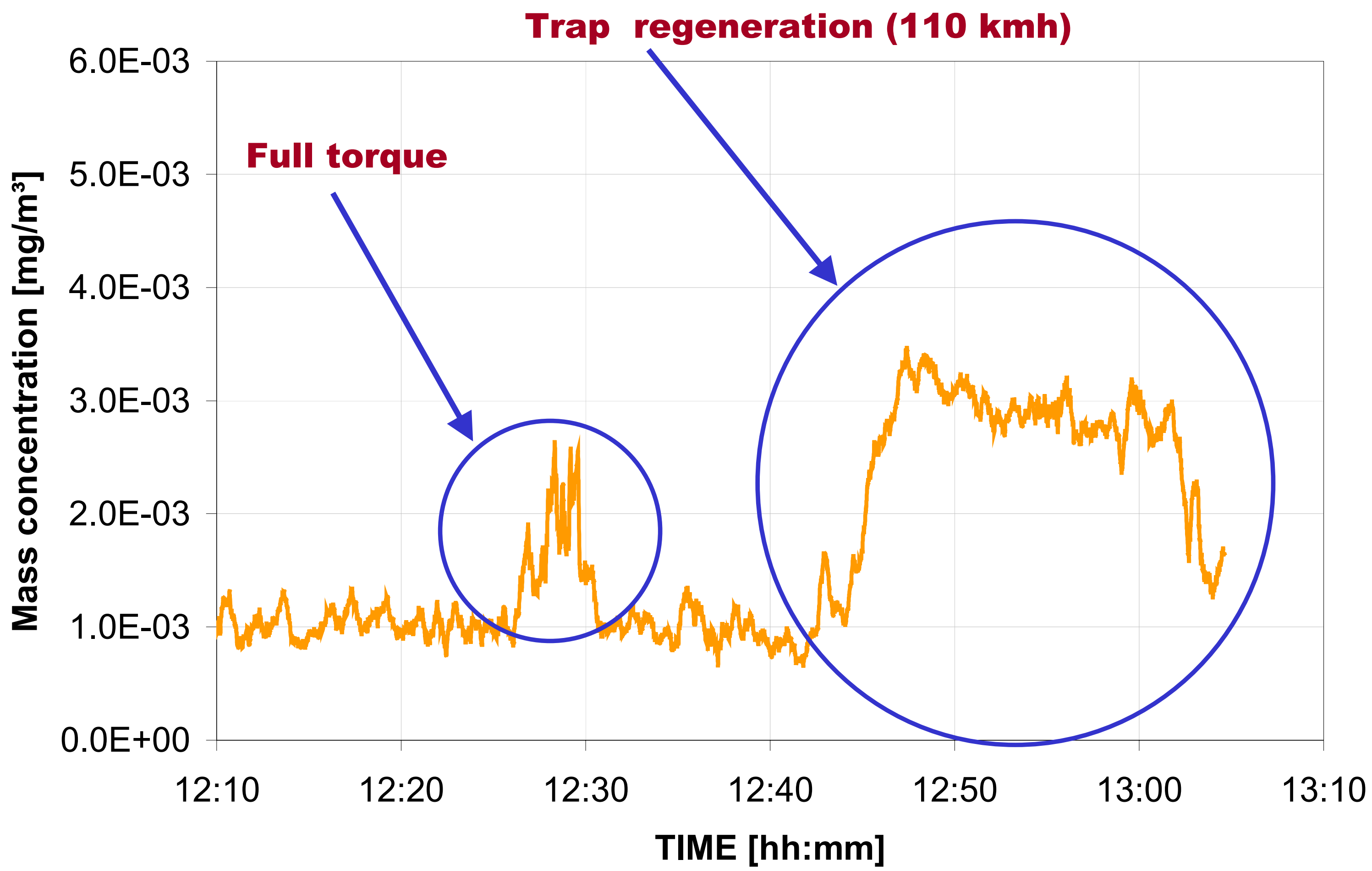


DMM data: sensitivity



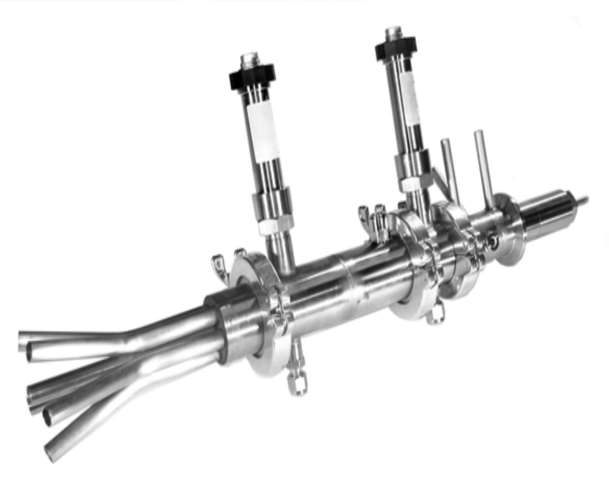
Trap regeneration, low emission

- Citroen C5 +trap, HDI (diluted, DR=65)



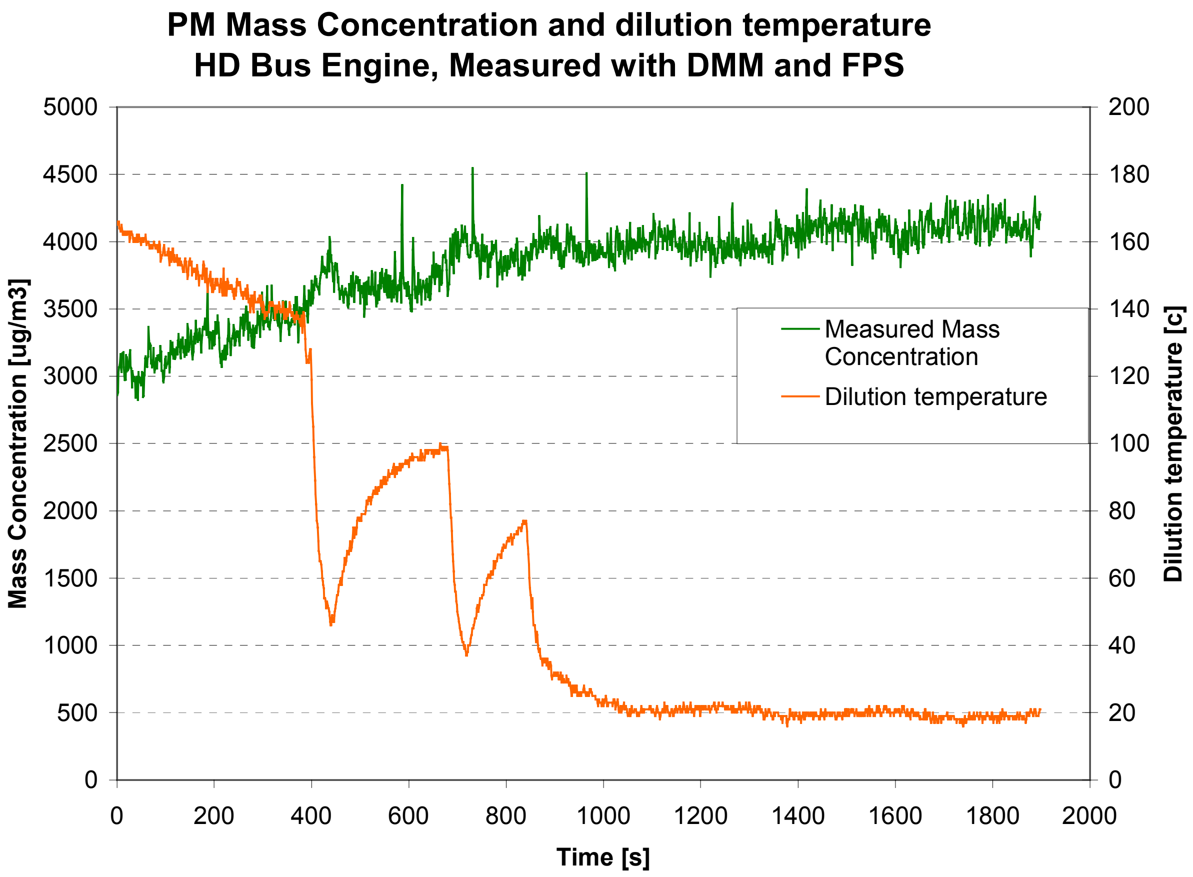
Solution 2: Tailpipe sampling

- Dekati Fine Particle Sampler FPS is a sampling system for tailpipe particle measurements
- Dilution parameters are controlled, including dilution ratio control in the range of 1:15-1:200, temperature control (10-300°C) and real-time dilution ratio determination
- FPS can take the sample from high overpressures in a controlled way.
- Suitable for all PM measurement devices



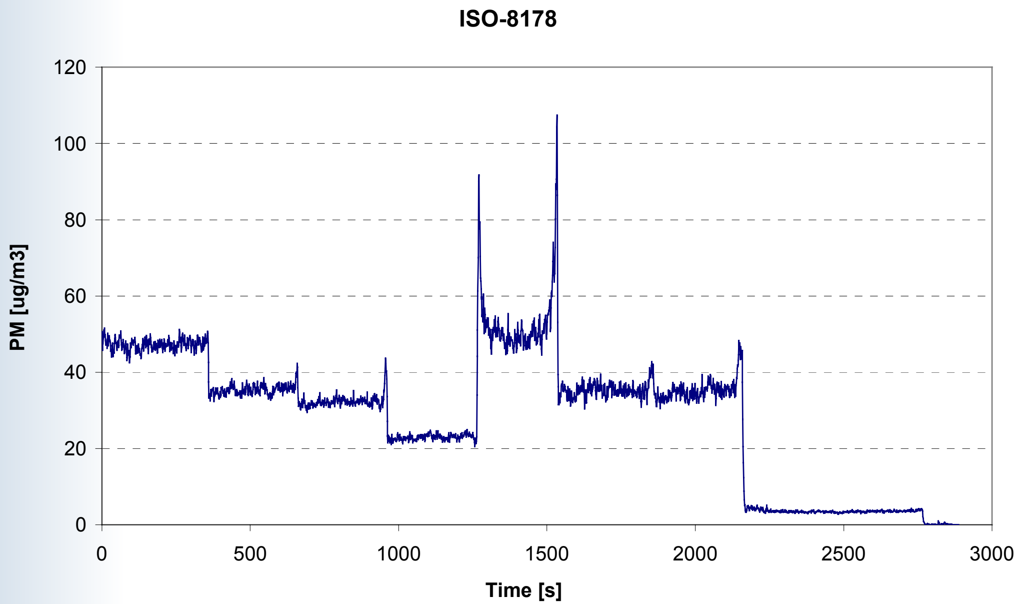
FPS results: Volatile material

Sampling temperature and dilution ratio have an effect on the measurement result

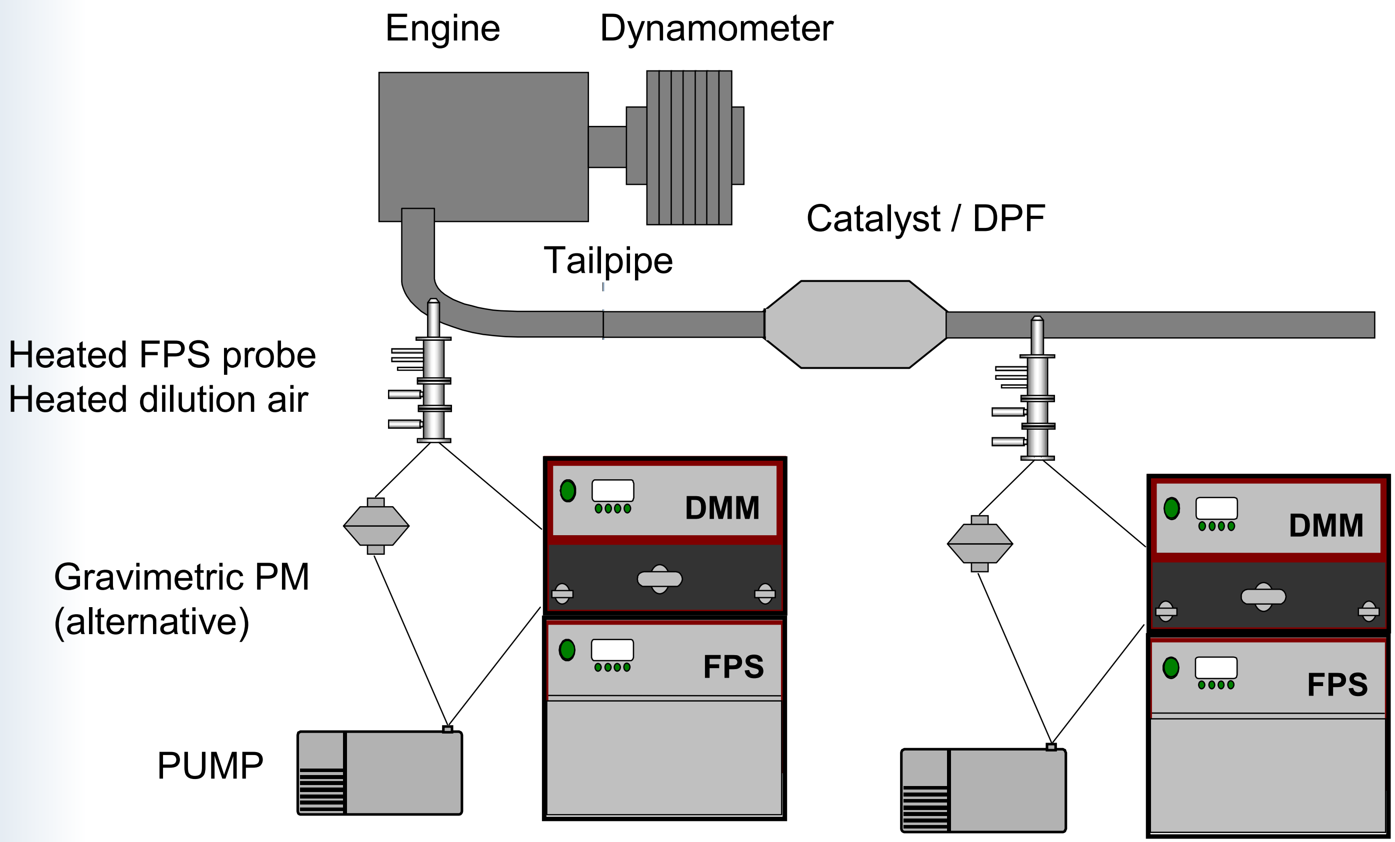


DMM-FPS

- A transportable system for both pre- and post-DPF measurements
- Real-time data of the tailpipe emission



Setup for real-time DPF efficiency measurement

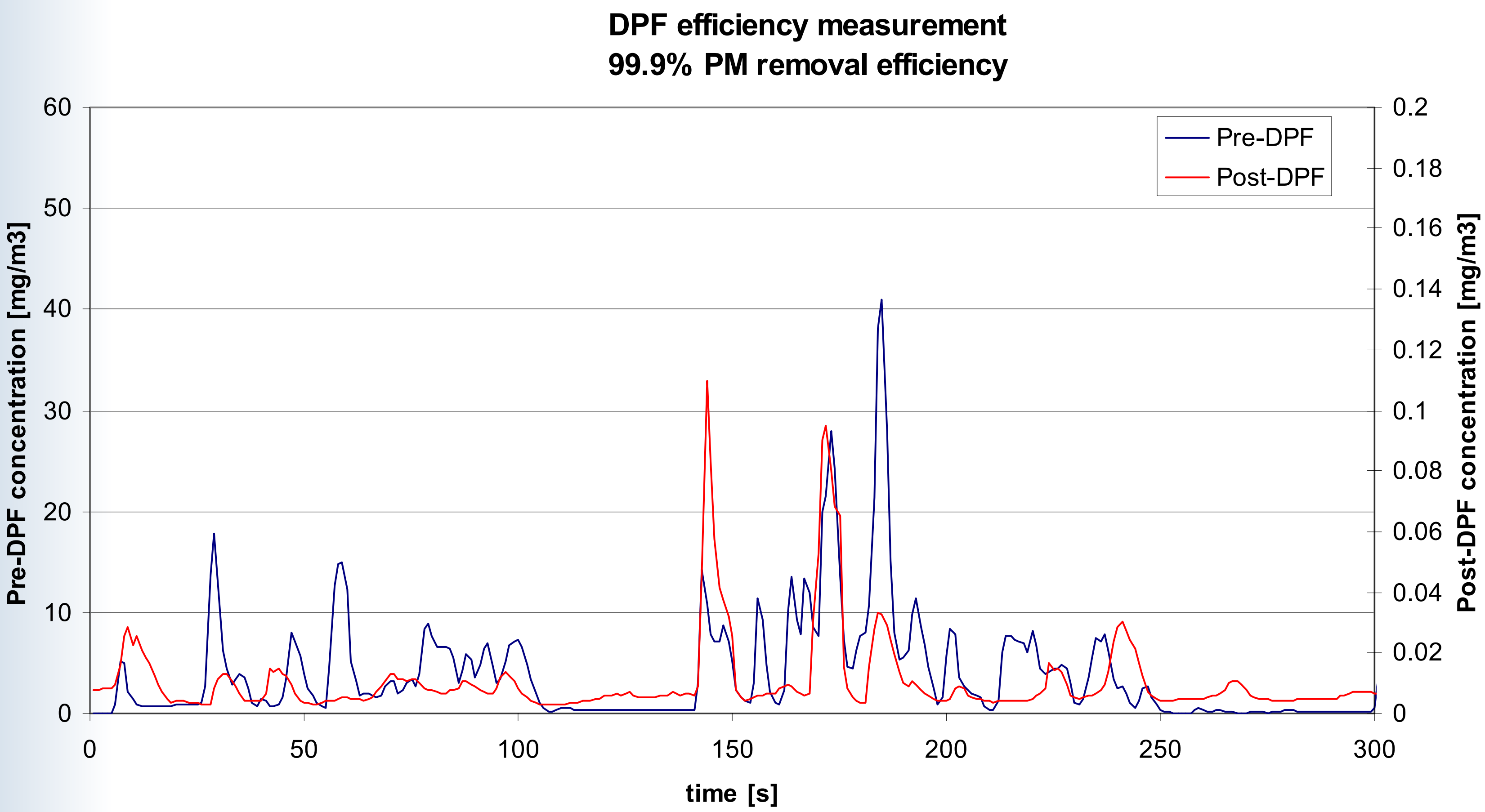


Results

- Number- and mass based measurements are reporting different efficiencies (Swiss PMP)

		Tailpipe concentrations [mg/Nm3, #/Ncm3]:	Ratio High / Low Efficiency %
EURO IV-Level engine	Gravimetry	2.16	7 (86%)
	DMM	2.56	512 (99.8%)
	CPC	7.9E+6	1410 (99.9%)
	ELPI	9.6E+6	1600 (99.9%)
Post-DPF	Gravimetry	0.31	
	DMM	0.005	
	CPC	5.6E+3	
	ELPI	6.0E+3	

Real-time data of DPF efficiency



Conclusions

- Volatile material affects to the aftertreatment device efficiency measurements
- Electrical detection of particles provides second-by-second data of PM emission with better sensitivity than gravimetric measurement and without filter artefact.
- Sensitive real-time data allows also DPF regeneration process studies
- FPS can take the sample from upstream and downstream DPF
- Tailpipe sampling allows better control over the dilution parameters, and in many cases is easier setup than the CVS tunnel measurement
- Dilution temperature control allows also particle composition studies

Thank you for your attention!

Problem: Filter artefact

- Gravimetric filter paper collects all solid particles, but also organic gas-phase material
- From aerosol measurement point of view, this gas-phase material is not PM. Hydrocarbons are measured separately.
- This artefact depends on the used filter material, TX-40 gives much higher masses than e.g. Teflo filters