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Optical, electrical mobility and aerodynamic measurements of soot particles before and after filter media in diesel exhaust

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ABSTRACT

The deployment of highly efficient Diesel engines in the future has the potential to contribute to the reduction of CO_2 emissions and to the significantly less transportation related impact on environmental pollution.

This deployment will be enabled by efficient methods to reduce particulate emissions from diesel engines. However, current engine technology seems to be incapable to achieve the future legislation standards and the only possible route towards this target is to implement suitable exhaust aftertreatment devices which are widely known as Diesel Particulate Filters (DPF) or particulate traps.

DPF's are capable of removing particulates from the exhaust gases based on various transport mechanisms (diffusion, thermophoresis etc). The effectiveness of a particulate filter depends upon two main factors, namely the filter media and its geometric configuration.

Filters are either of metallic or ceramic nature. Their geometric configurations include extruded honeycomb wall-flow monoliths, assembled parallel plate wall-flow elements, cylindrical cartridges based on fibrous structures, foam monolithic blocks and plates or concentric tubular wall-flow elements.

In this presentation a number of filters of different type and geometric configuration were selected to be evaluated in terms of their particle collection efficiency. The configuration chosen were extruded wall flow monoliths and cylindrical cartridges incorporating fibrous structures.

Measurements were carried out in the raw exhaust of a turbo-charged Direct Injection Diesel engine employing a newly developed laser particle sensor with an adjustable optical path length. Additional measurements were also taken employing a Scanning Mobility Particle Sizer (SMPS) in the diluted exhaust of the same engine as a reference instrument. Aerodynamic measurements with an Electric Low Pressure Impactor gave much lower particle concentrations than the other techniques and were not used for filtration efficiency assessment

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INTRODUCTION-MOTIVATION

- **WHAT: Study of the filtration characteristics of various media for diesel particles**

- **WHY: New filter media and structures are continuously developed, hence a need for a systematic approach and understanding**

- **HOW: Various experimental techniques and mathematical modeling to create a filter media performance database**

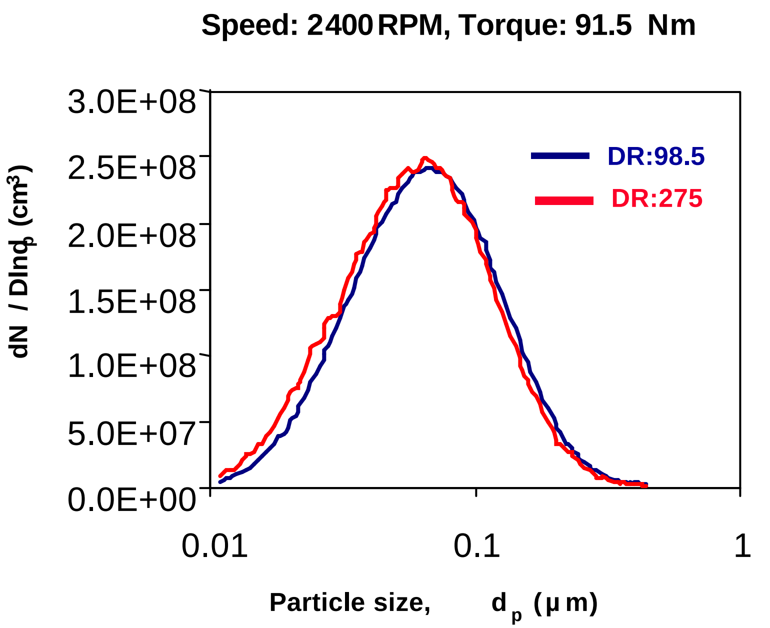
- **WHO: Filter developers, application & customer support engineers, emission control systems manufacturers**

OVERVIEW

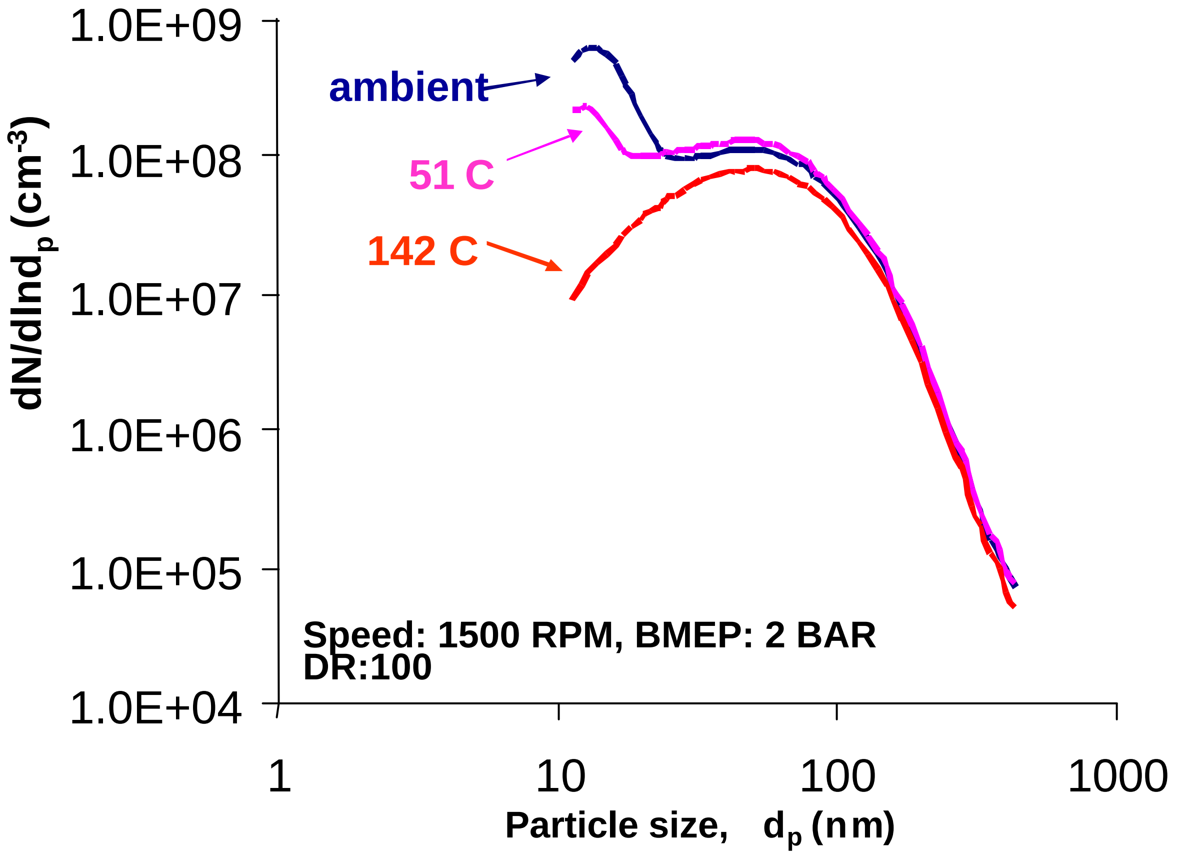
- **Measurement techniques employed**
  - **Electrical Mobility (SMPS)**
  - **Long Path Multiwavelength Extinction (LPME)**
  - **Low Pressure Impaction (ELPI)**
  - **Raw Exhaust gravimetric Sampling (RES)**

- **Filter media employed**
  - **Extruded Wall-Flow (2 non-oxide, 1 oxide ceramic)**
  - **Fibrous Textile (3 structures)**

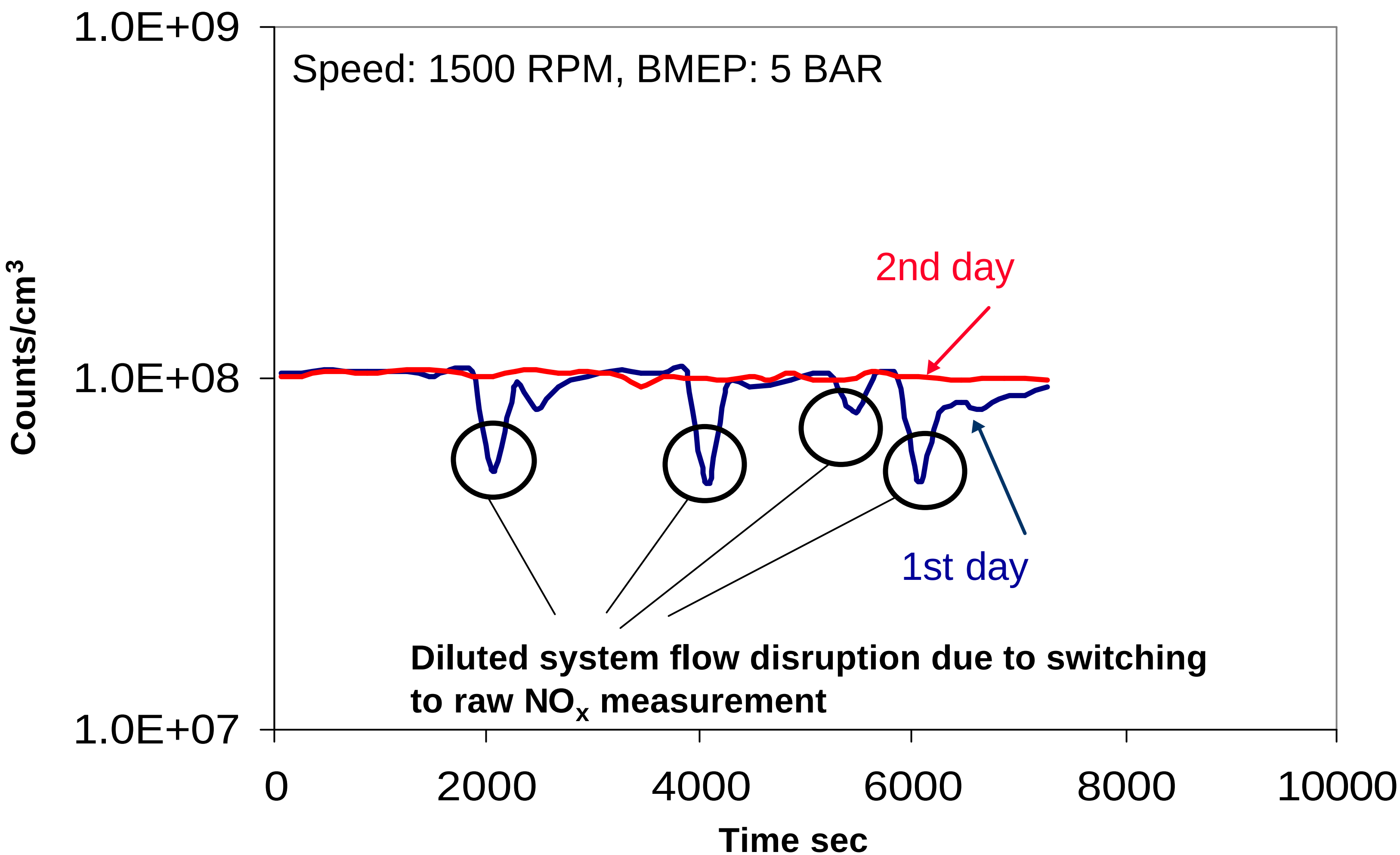
INFLUENCE OF SAMPLING CONDITIONS ON SMPS MEASUREMENTS



Diluter Temperature is the most important parameter!

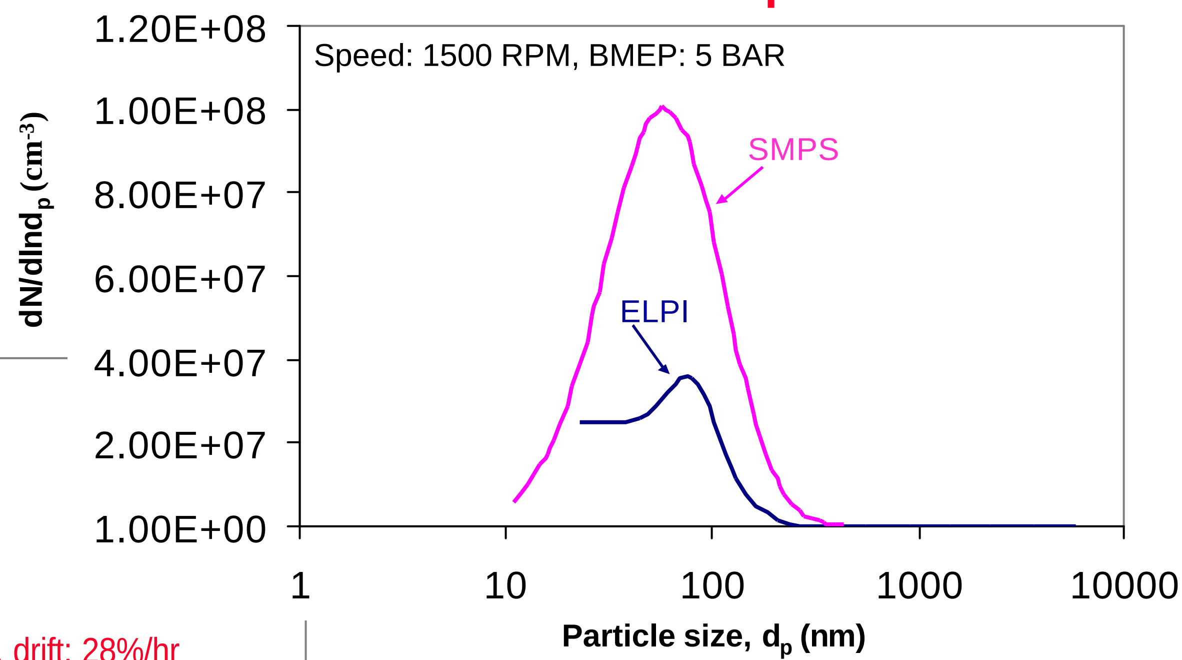


SMPS REPEATABILITY

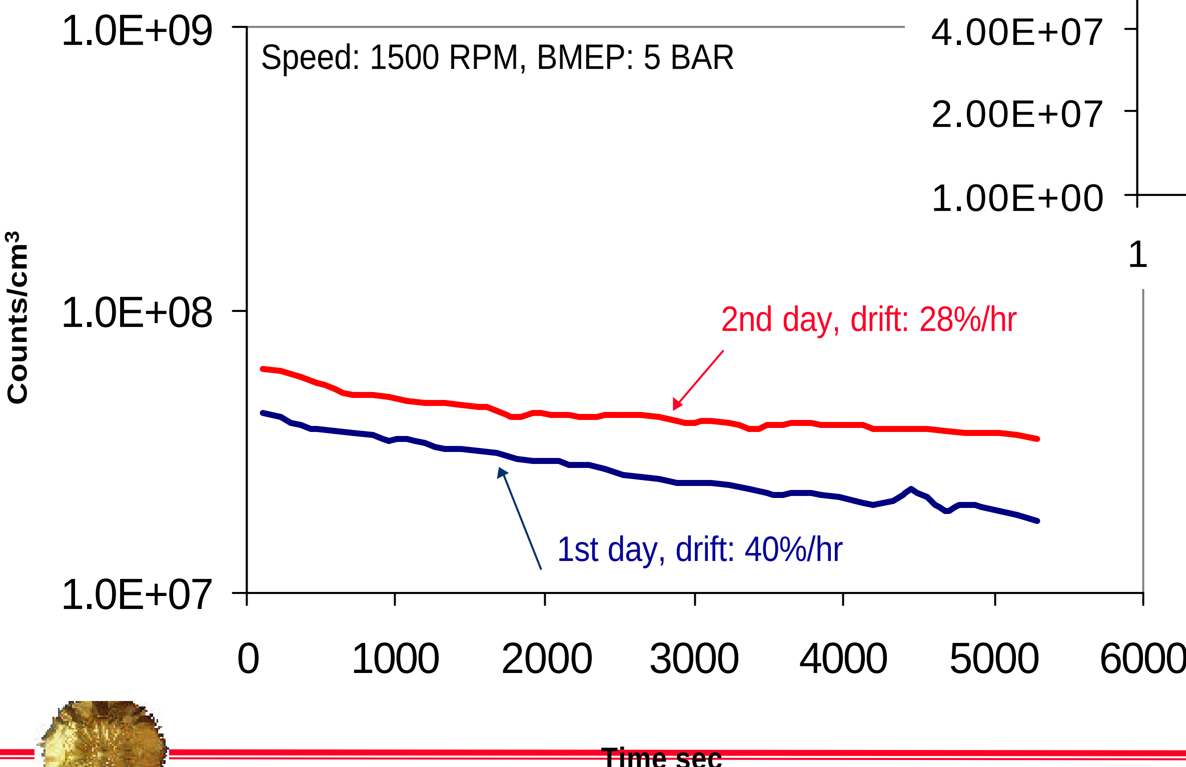


ELPI MEASUREMENTS

Particle losses compared to SMPS

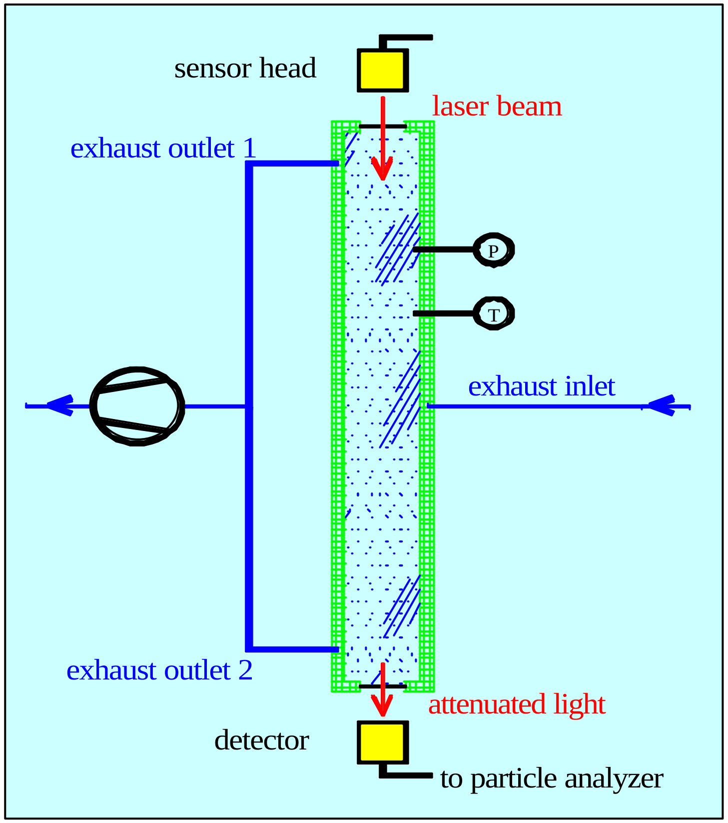


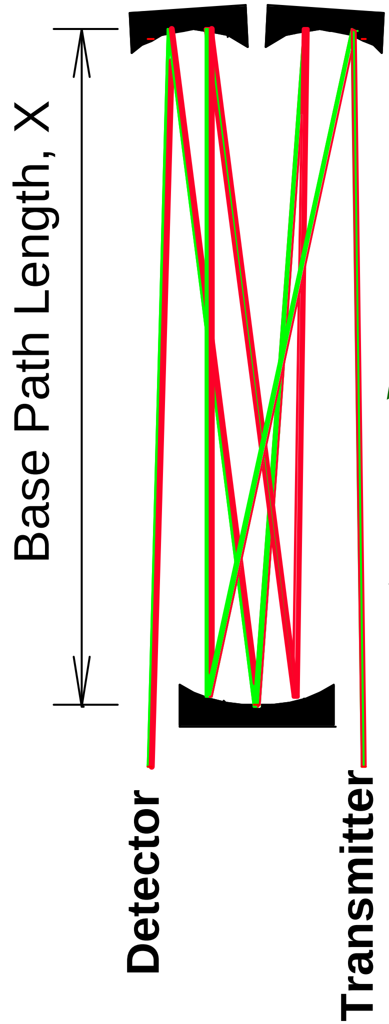
Not good repeatability



LONG PATH MULTIWAVELENGTH EXTINCTION (LPME) PARTICLE SENSOR

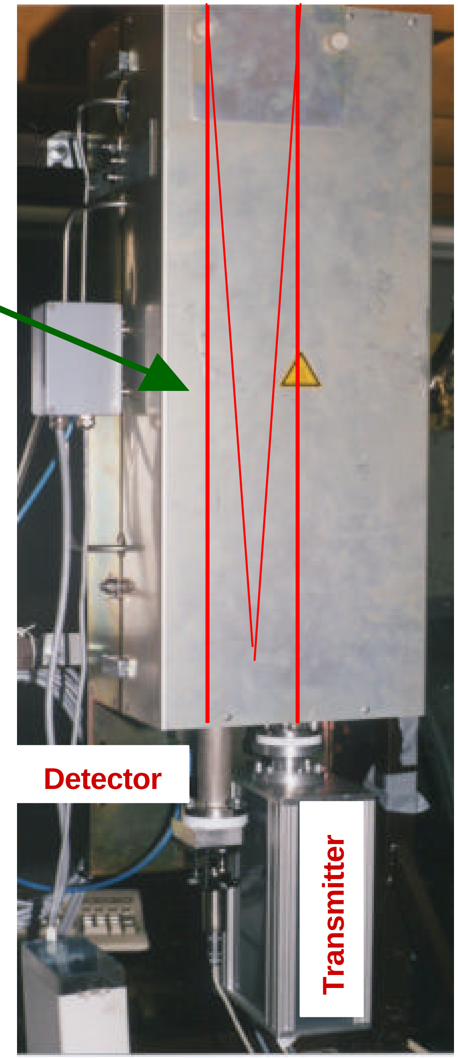
(In collaboration with WIZARD ZAHORANSKY KG)



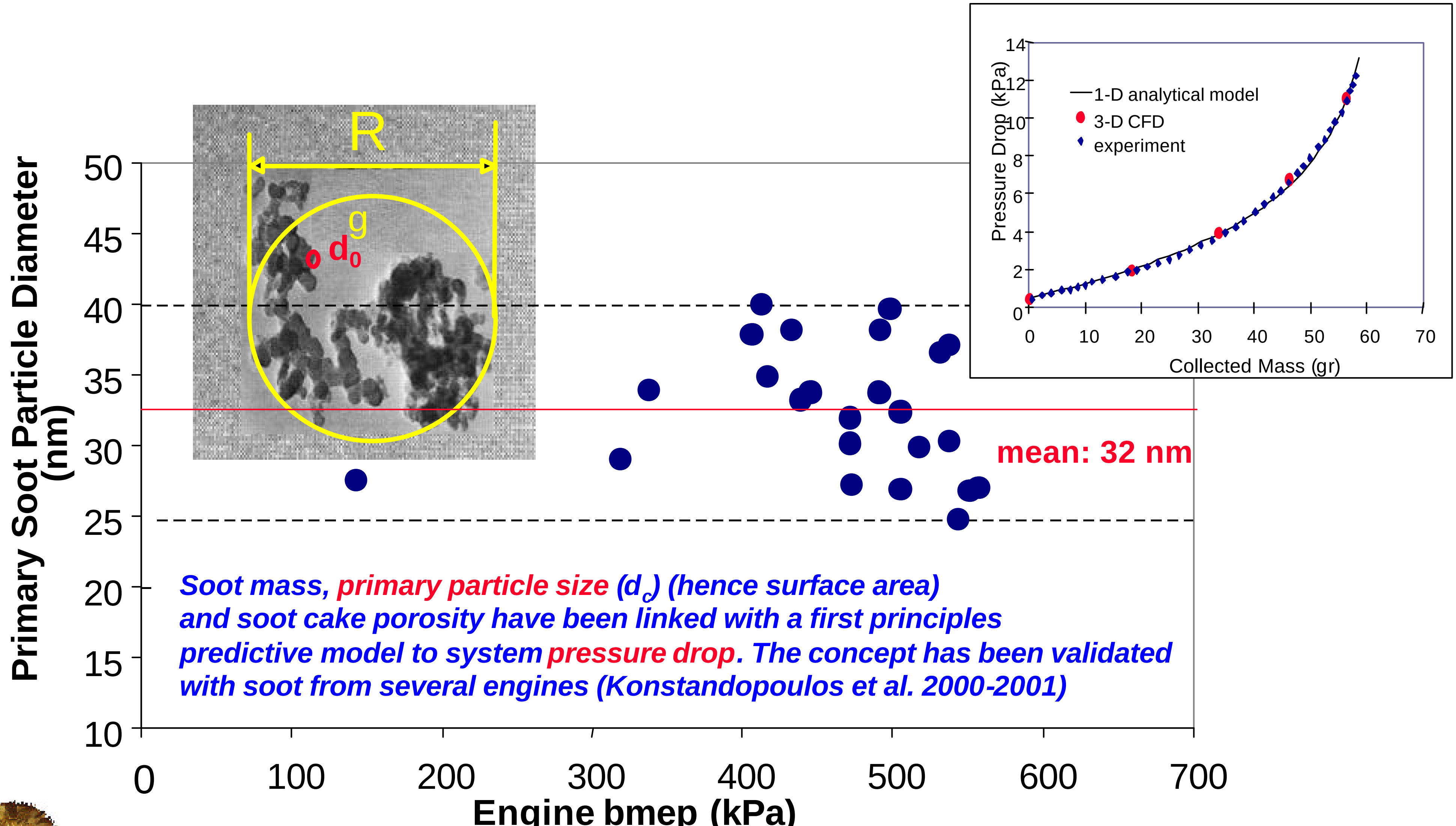


Adjustable optical path (10-20 m)

3 laser wavelengths: 638, 813 & 1315 nm



Estimation of mean primary soot particle size from cake permeability



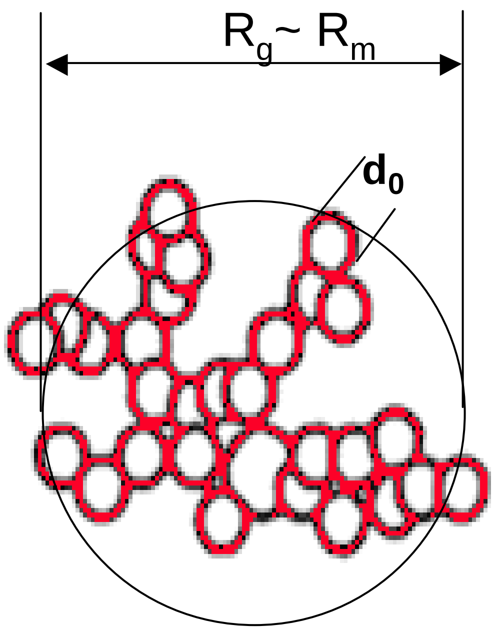
Soot mass, primary particle size (d_c) (hence surface area) and soot cake porosity have been linked with a first principles predictive model to system pressure drop. The concept has been validated with soot from several engines (Konstandopoulos et al. 2000-2001)

SMPS vs. LPME CORRELATION

STEPS

1. **Diesel particles are fractal aggregates of primary particles with size d_0 = 32 nm**
2. **The fractal dimension is that of DLCCA, D_f = 1.82**
3. **The aggregate radius of gyration R_g scales with the SMPS electrical mobility diameter R_m**
4. **LPME measured volume fraction is reference quantity (cf. Rayleigh limit)**

$$V_f = ln(\frac{I_o}{I})\frac{l}{36pF(l)}$$



5. **The number of primary particles per aggregate is then**

$$\tilde{N} = k_g(\frac{2R_g}{d_0})^{D_f} = k_m(\frac{2R_m}{d_0})^{D_f}$$

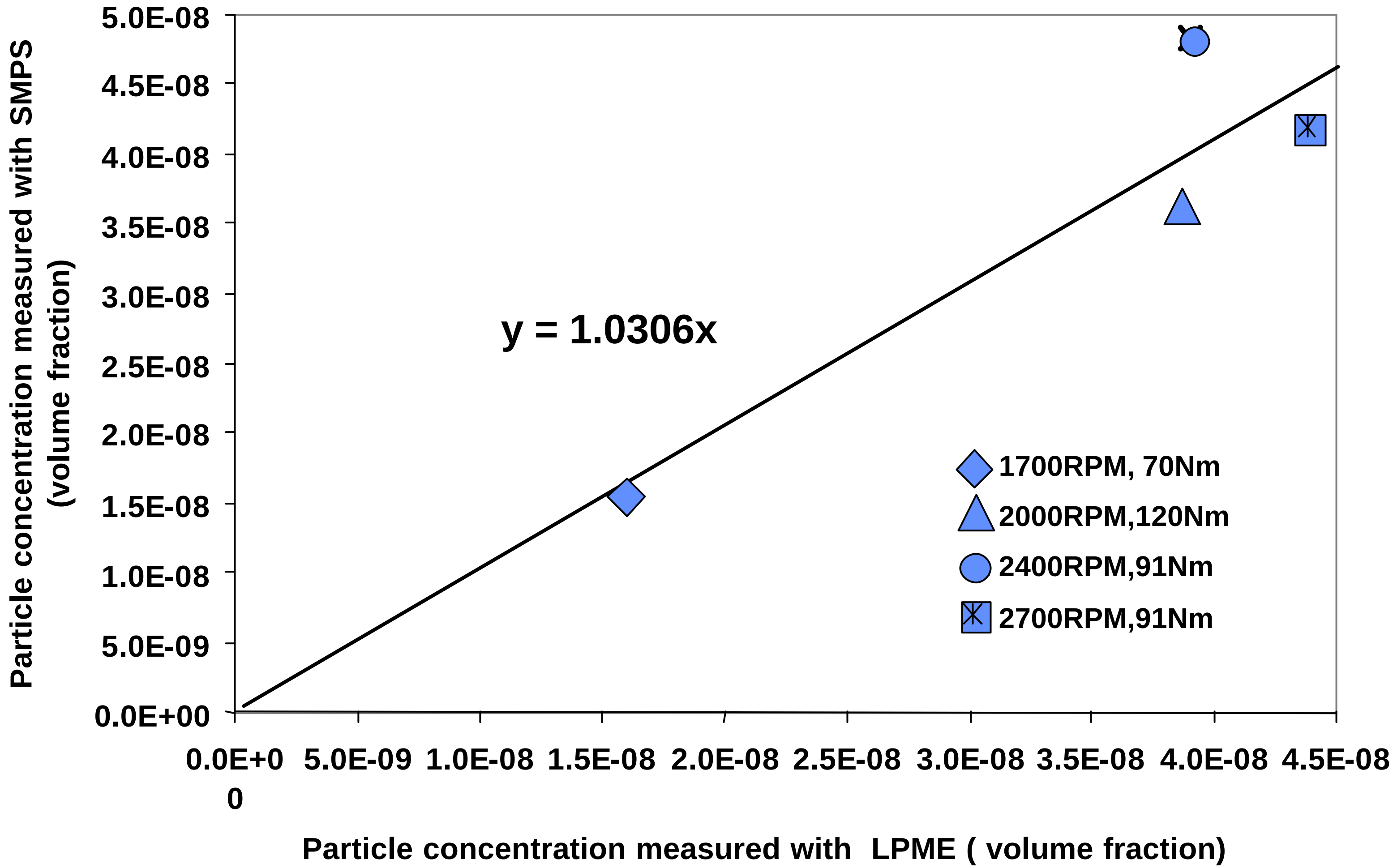
6. **SMPS volume fraction is computed summing up over the histogram of diesel aggregates, N_i**

$$V_f = \sum_{i=1}^{n} N_i * \tilde{N}_i * \frac{p}{6} d_0^{\,3}$$

COMPARISON OF LPME vs. SMPS CONCENTRATION

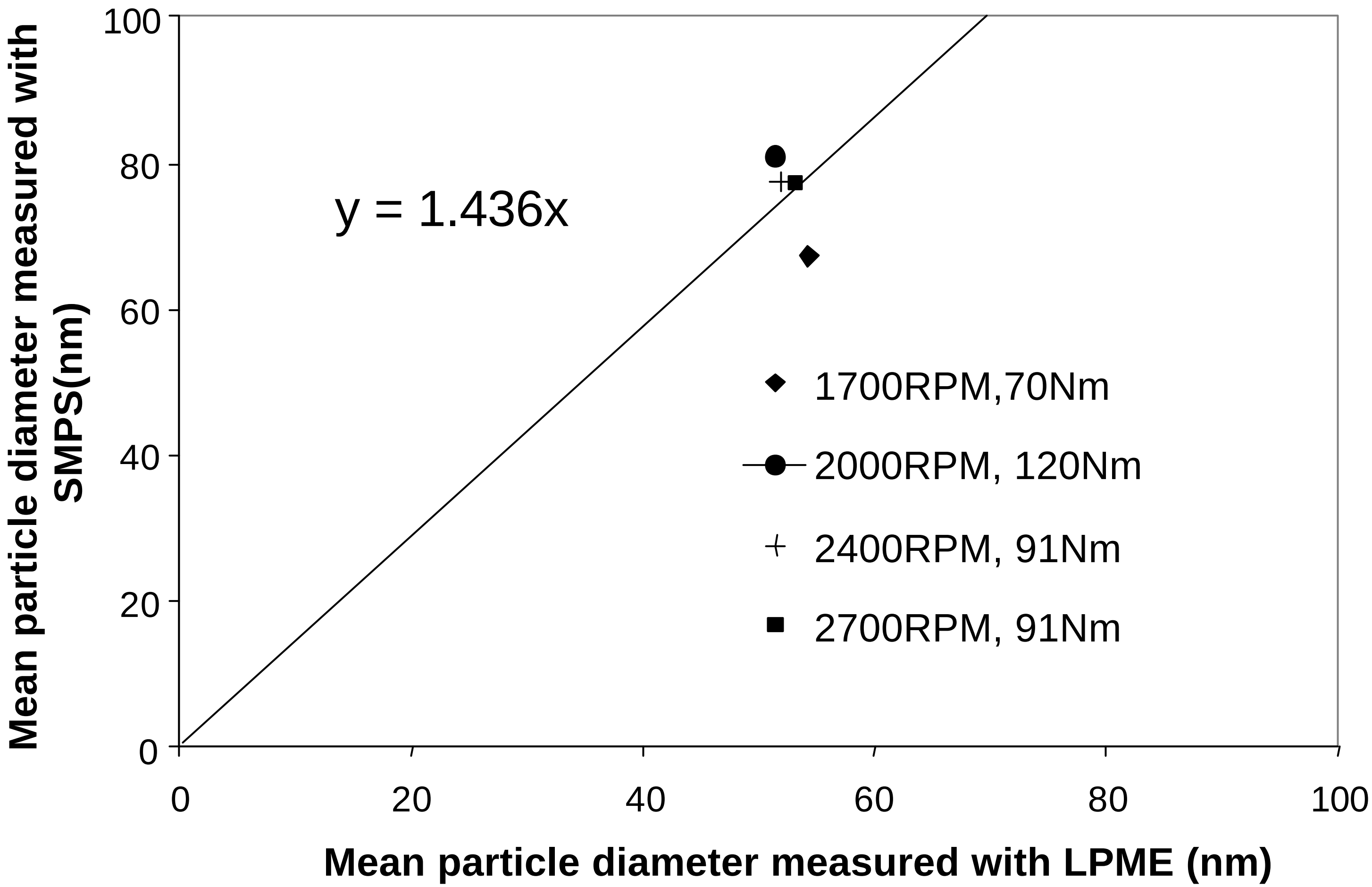
Conversion of SMPS data assuming fractal particles

k_m=3.9±0.2 D_f=1.82 d_0=32 nm

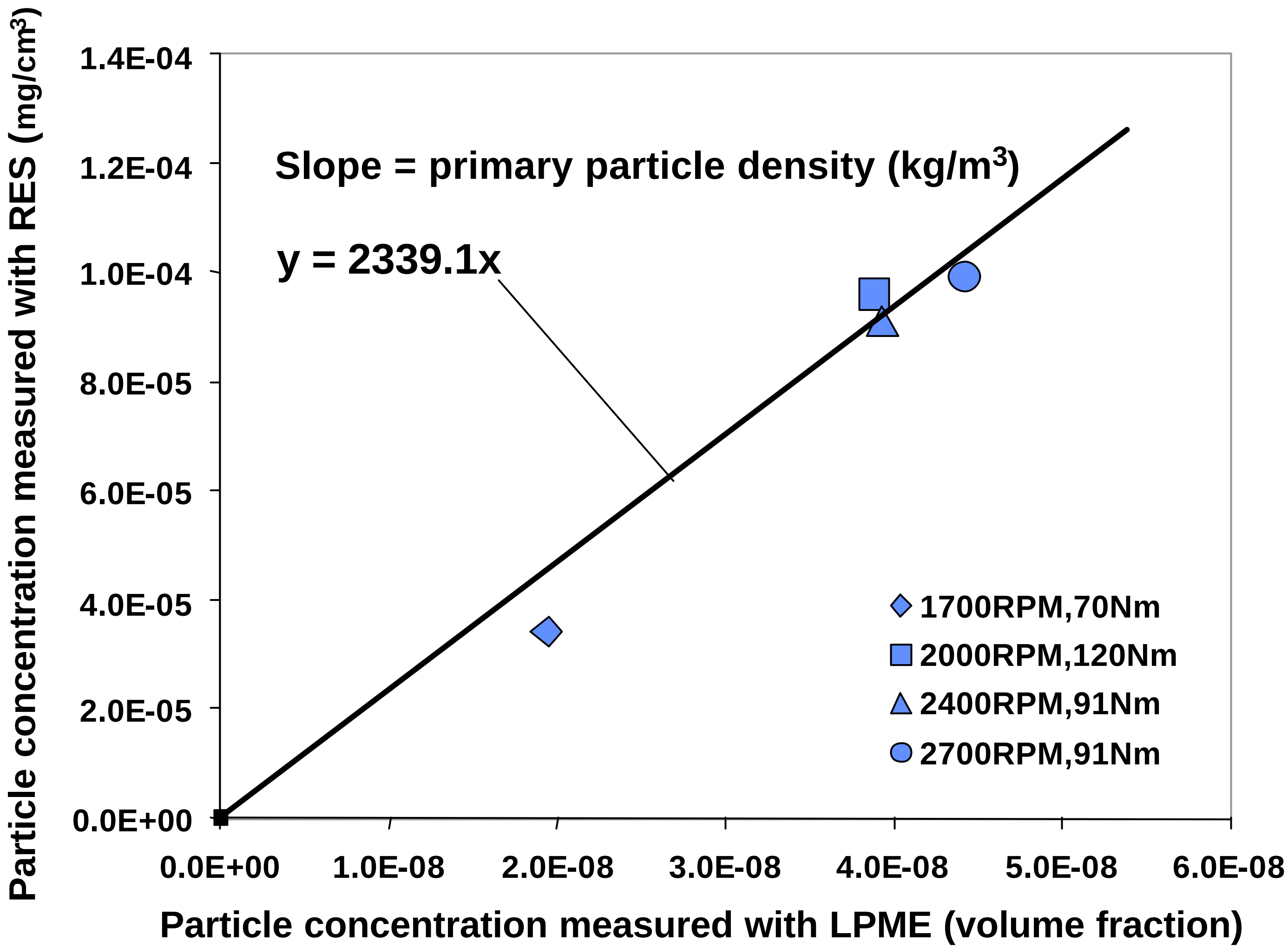


COMPARISON OF LPME vs. SMPS MEAN SIZE

LPME size is based on Mie equivalent sphere



COMPARISON OF LPME vs. RES CONCENTRATION

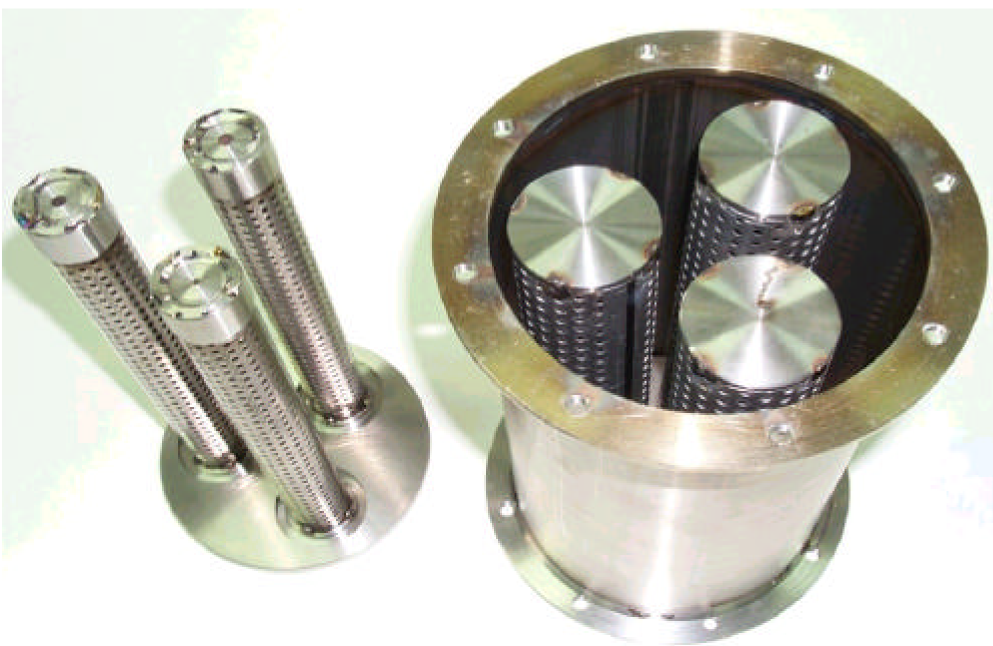


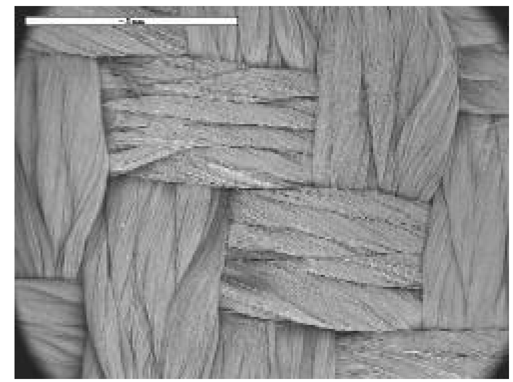
FILTER MEDIA TESTED:
Extruded ceramics

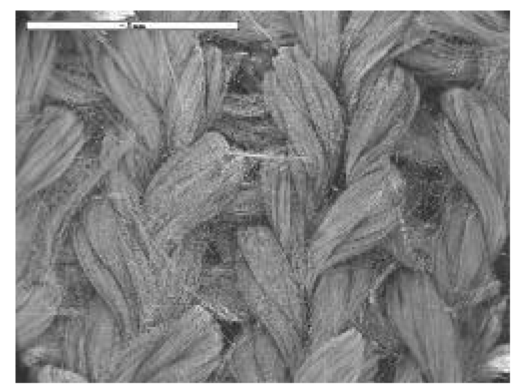
Filter	Sample A	Sample B	Sample C
Media	**Non-oxide**	**Non-oxide**	**Oxide**
Dimensions (in)	**5.66 x 7**	**5.66 x 6**	**5.66 x 6**
Permeability(m^2)	**1.8 E-12**	**2.5 E-12**	**6.2 E-13**
Cell density(cpsi)	**79**	**92**	**88**
Porosity(%)	**45**	**36**	**48**
Pore size (μm)	**25**	**11.14**	**12**

FILTER MEDIA TESTED:
Fibrous Textiles

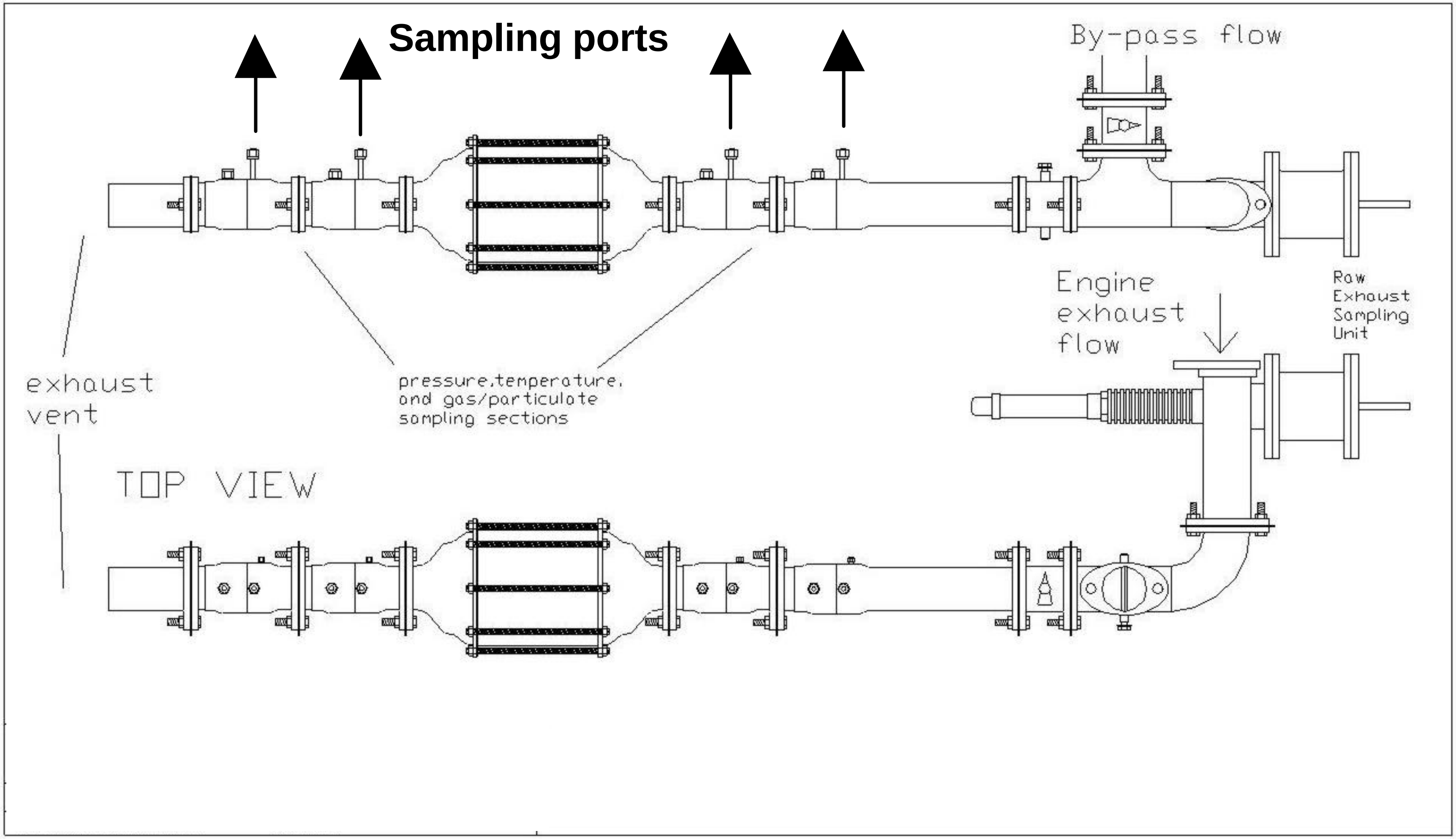
Filter type	Sample D	Sample E	Sample F
Permeability (m^2)	**$2.23*10^{-11}$**	**$2.54*10^{-10}$**	**$1.80*10^{-10}$**



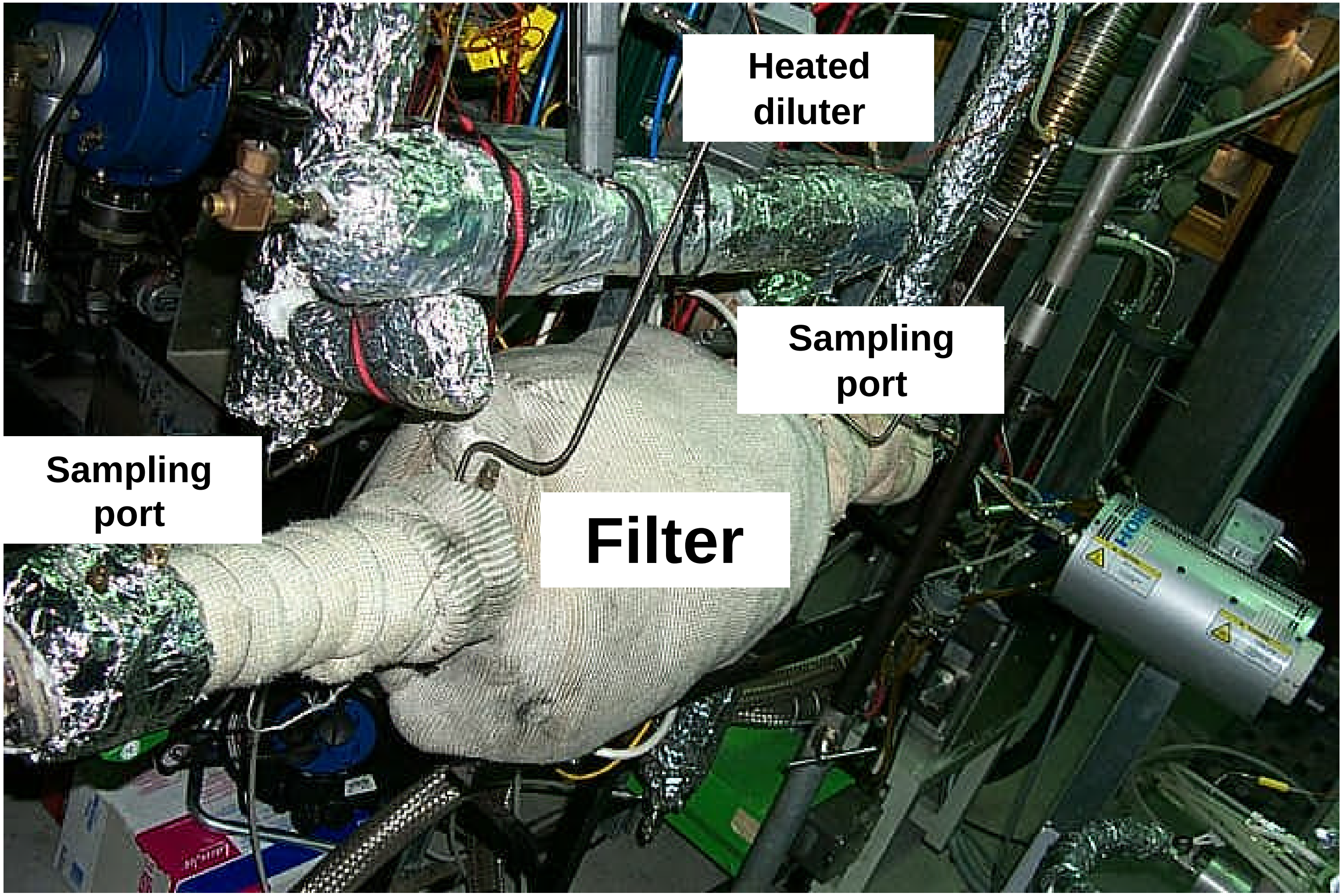




MEASUREMENT SET-UP

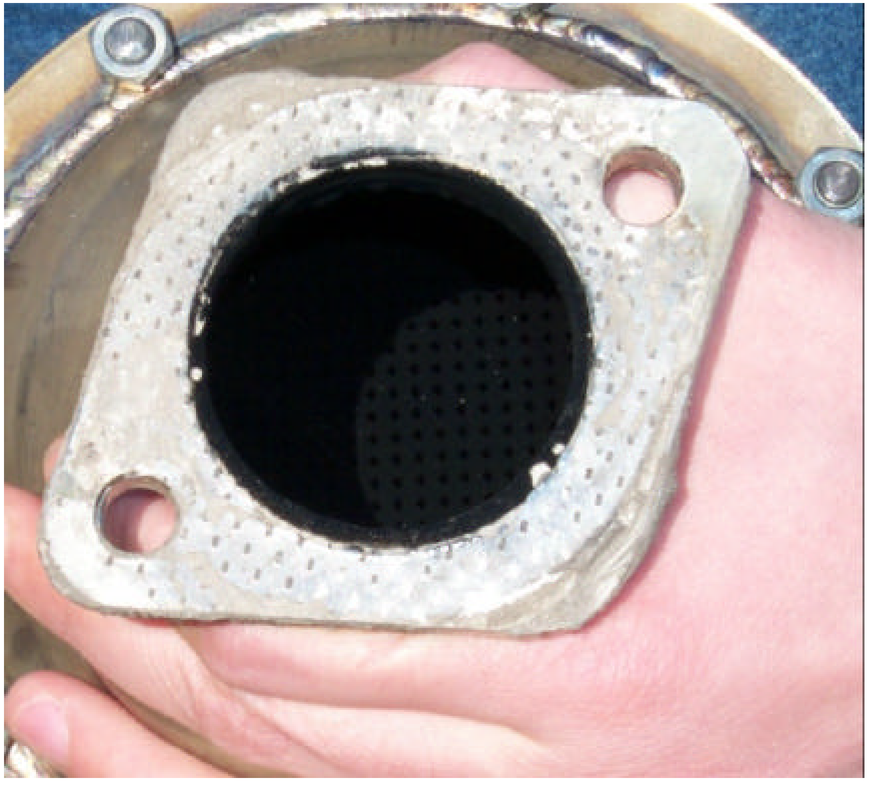


MEASUREMENT SET-UP

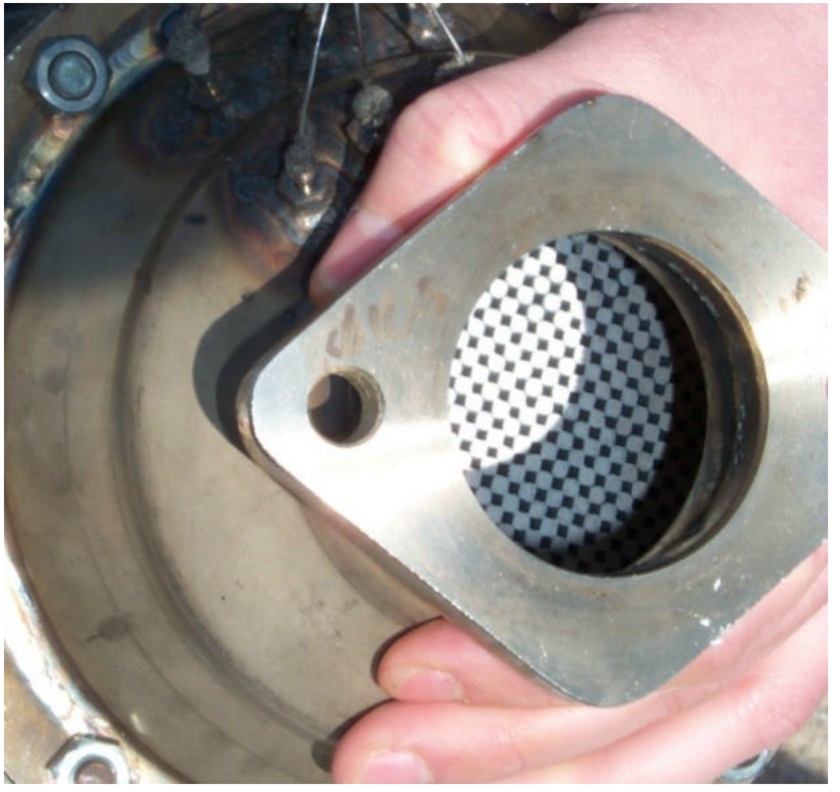


Filter Visual Inspection

Upstream face

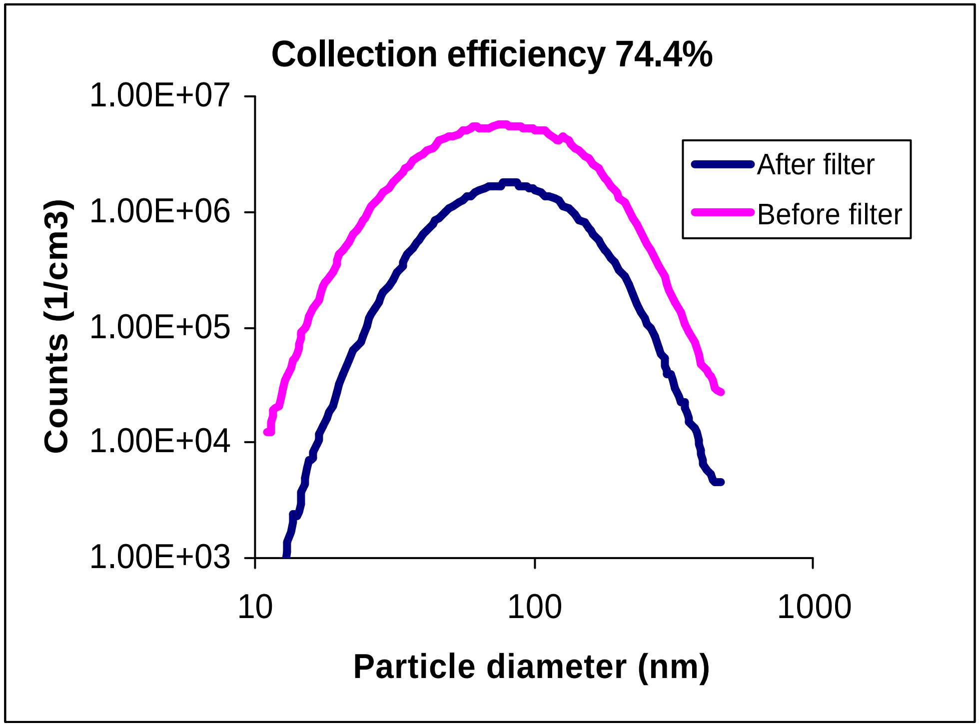


Downstream face

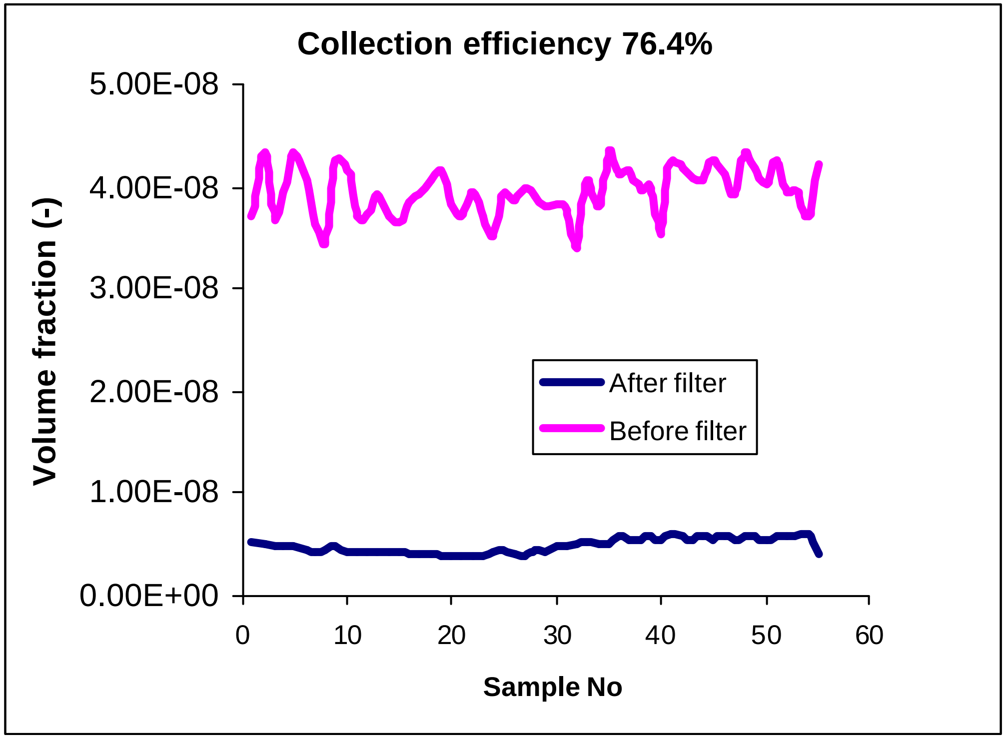


Filter Sample A Characterization

SMPS

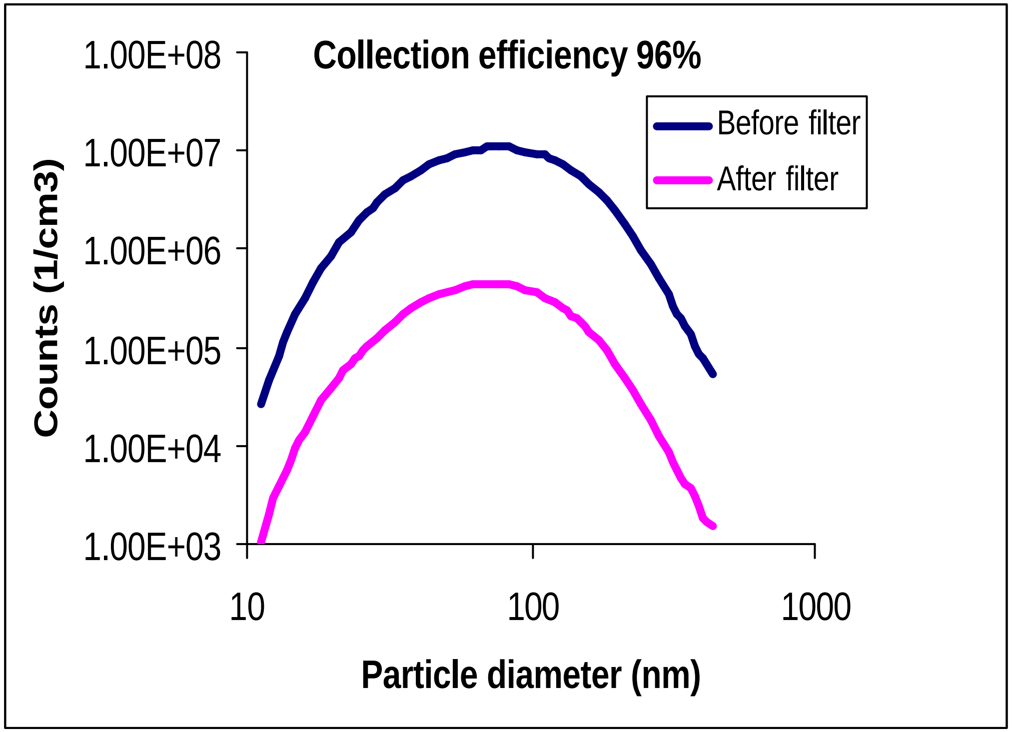


LPME

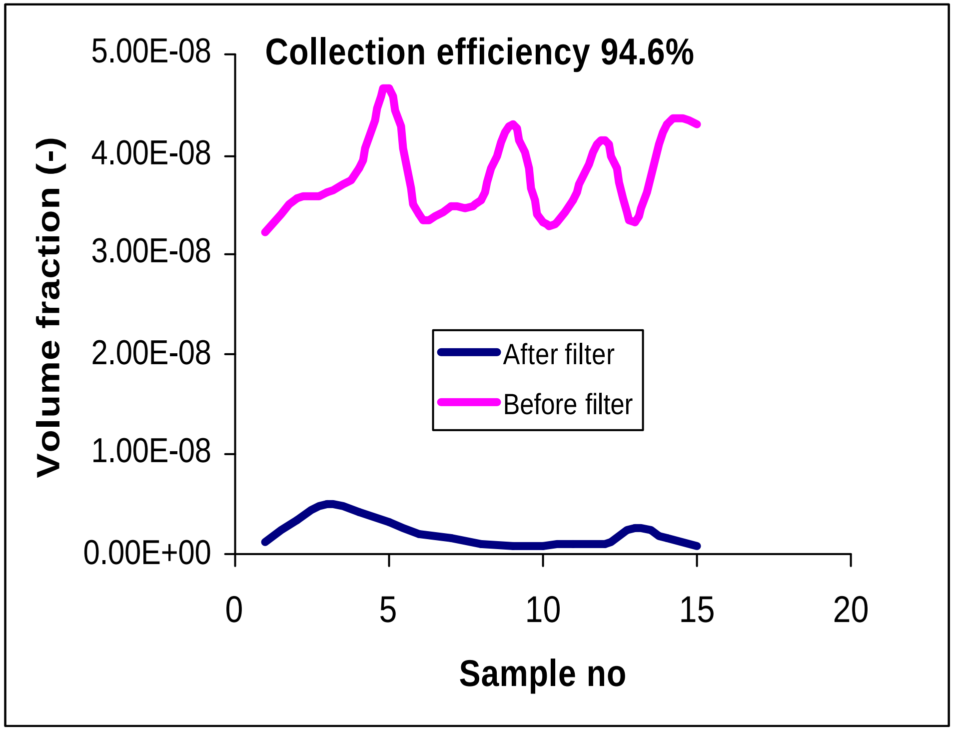


Filter Sample C Characterization

SMPS

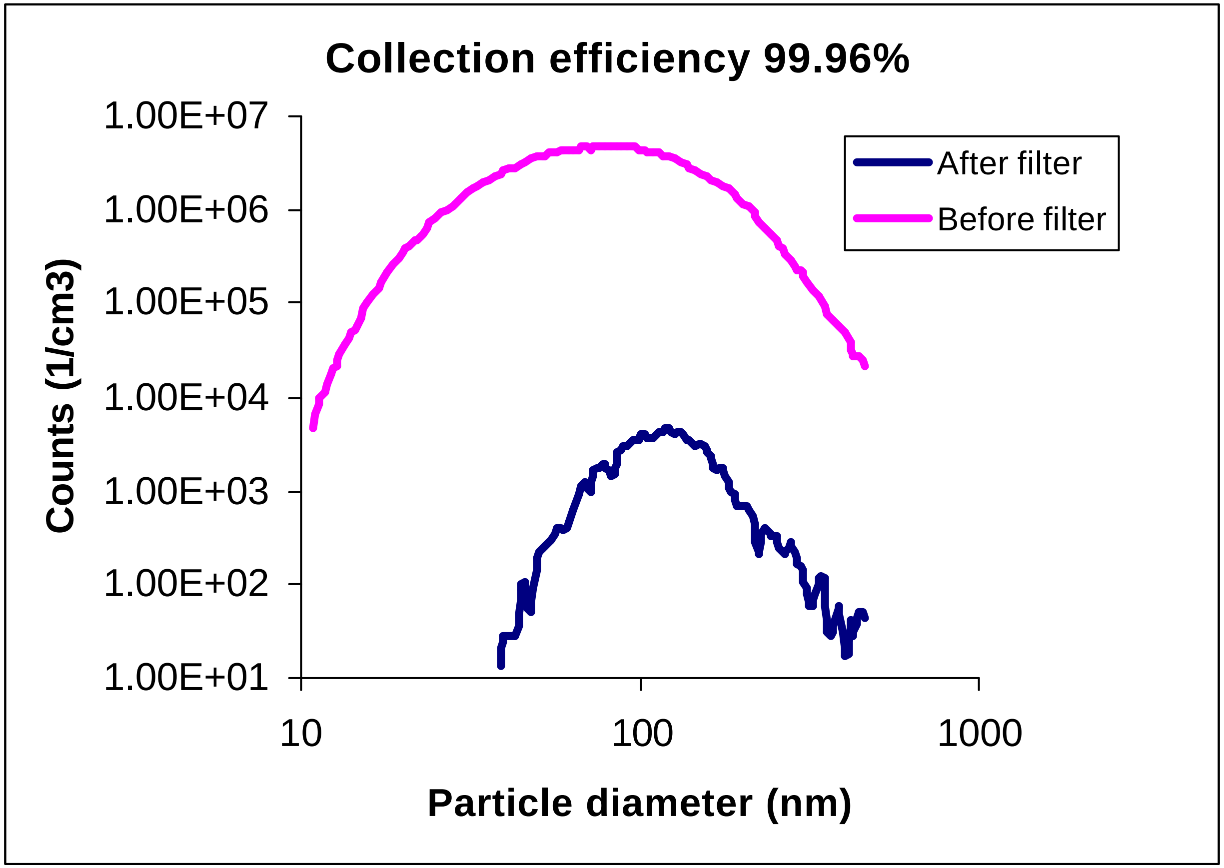


LPME



Filter Sample B Characterization

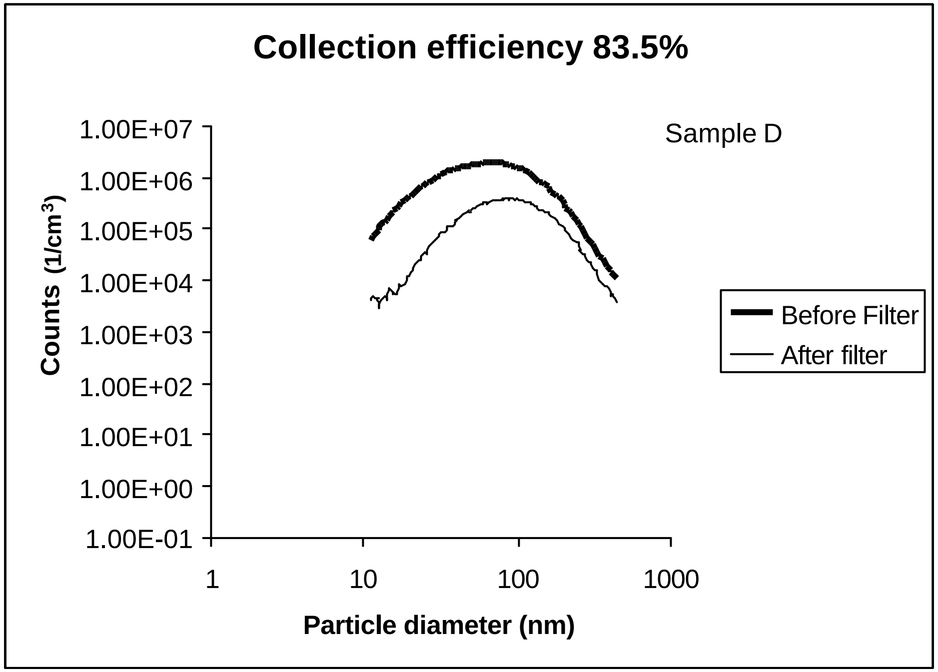
SMPS

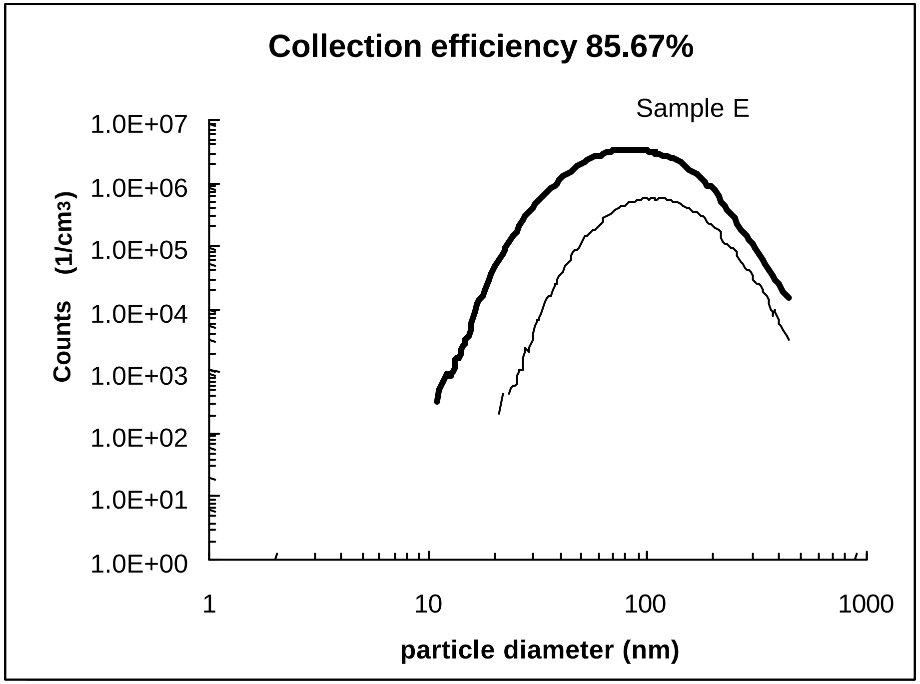


Extinction was more than 95% with the LPME and no reliable measurement was made

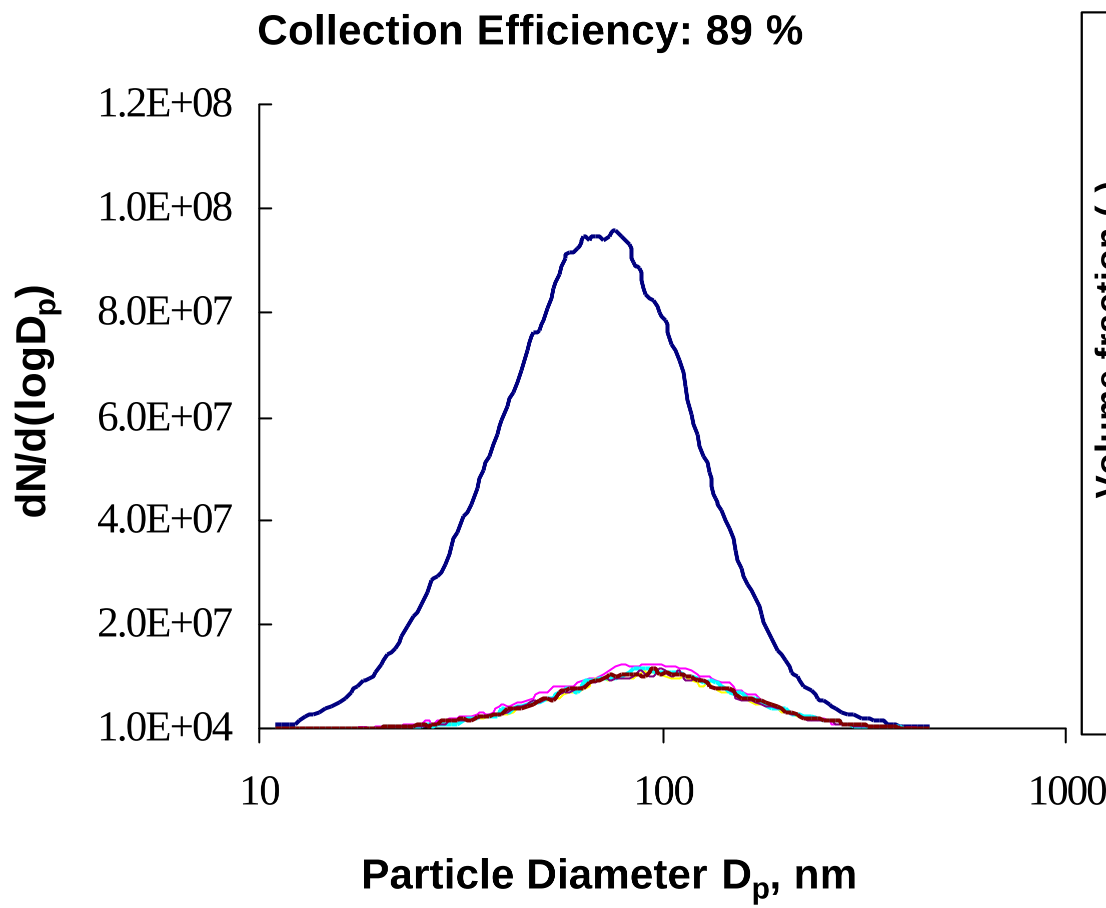
Filter Sample D & E Characterization

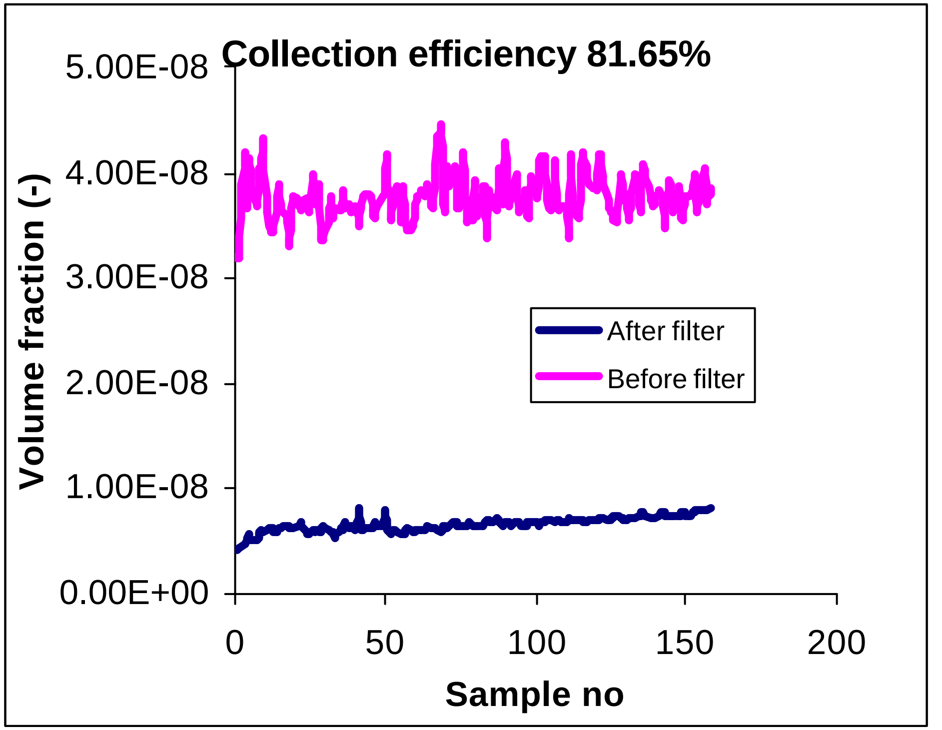
SMPS





Filter Sample F Characterization





Conclusions

- Long Path Multiwavelength Extinction (LPME) is a promising real time technique for measuring diesel particle concentration upstream and downstream of particulate filters

- SMPS, LPME and Raw Exhaust gravimetric sampling (RES) correlate very well assuming that diesel aggregates have D_f=1.82, d_0 = 32 nm and the density of primary particles is 2.3 gr/cm^3 (carbon). The fractal pre-factor determined from the data was found to be 3.9±0.2, in good agreement with literature values

- ELPI measurements were not reliable enough to be employed for filter performance characterization

- Collection efficiency of various prototype diesel particulate filters (extruded and fibrous textiles) was measured with the SMPS and LPDE and good agreement was found between both techniques

Acknowledgements

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