Real Time Particulate Mass Measurements Pre and Post Diesel Particulate Filters (DPF's) for Light- Duty Diesel Vehicles

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Outline

- Challenges of measuring PM at a Pre-DPF Location
  - *Rapid Temperature changes*
  - *Very fast pressure changes*
  - *Water and volatile PM fraction issues*
- Sampling, Conditioning & Measurement Solution
  - *Theory of operation*
  - *Unique features*
  - *Operating conditions*
- Results
- Conclusions

Sampling Challenges – Pre and Post DPF

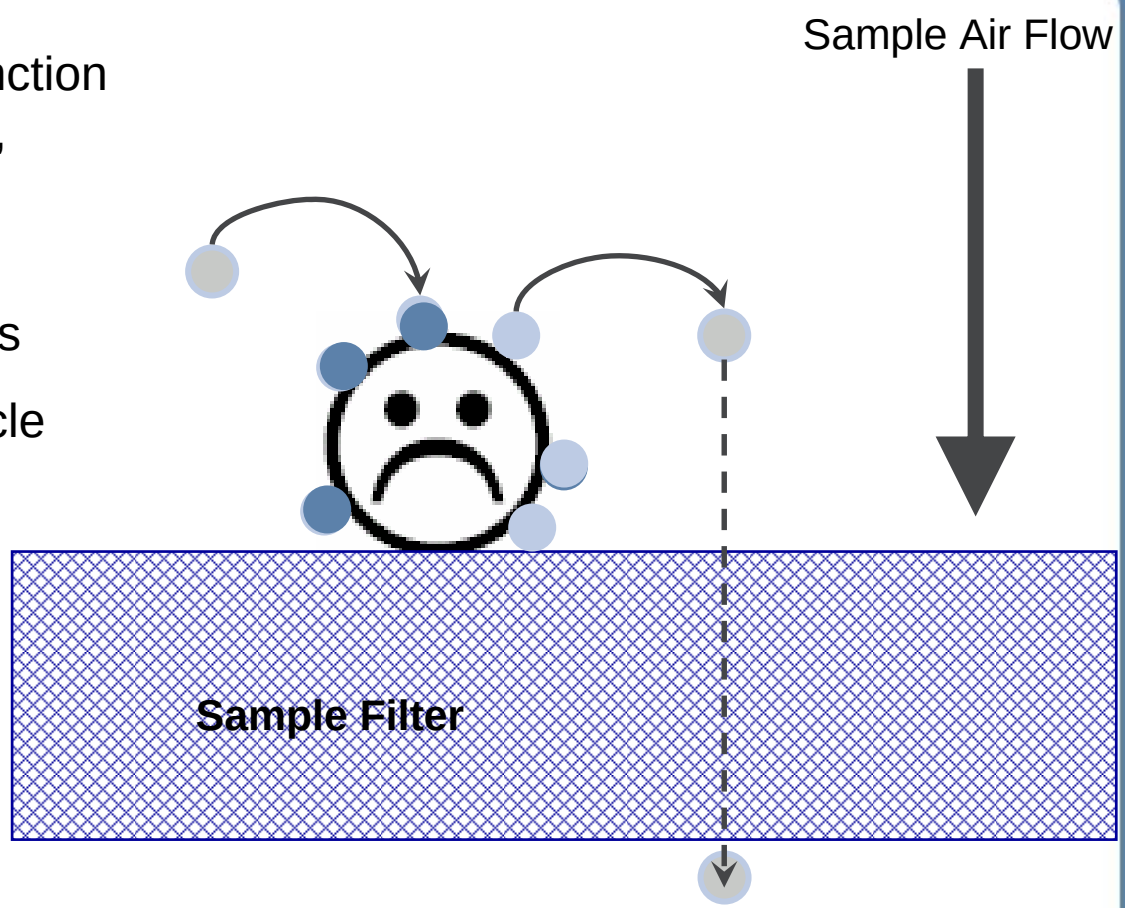
- Transient Cycles can produce temperature changes over the cycle effecting particle formation and filter temp
- More importantly – Pressure changes in the exhaust pipe due to engine changes and DPF backpressure changes can effect sampling and dilution ratio parameters.
- Potential of water condensation due to rapid cooling/dilution can impact particle losses
- Dilution Residence Time can impact secondary particle mass formation

Sampling Artifacts

Gas-particle equilibrium is a function of temperature, vapor pressure, humidity:

- relative humidity increase → particle may take on water mass

- temperature increase → particle may lose semivolatile organic material mass



= particle phase molecule (e.g., H_2O, SVOC, NH_4NO_3)

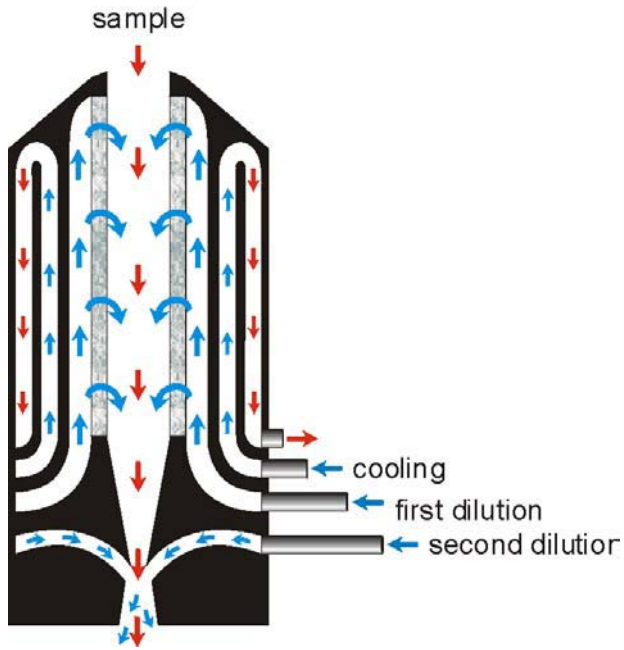
= gas phase molecule (e.g., H_2O, SVOC, SO3)

Solution

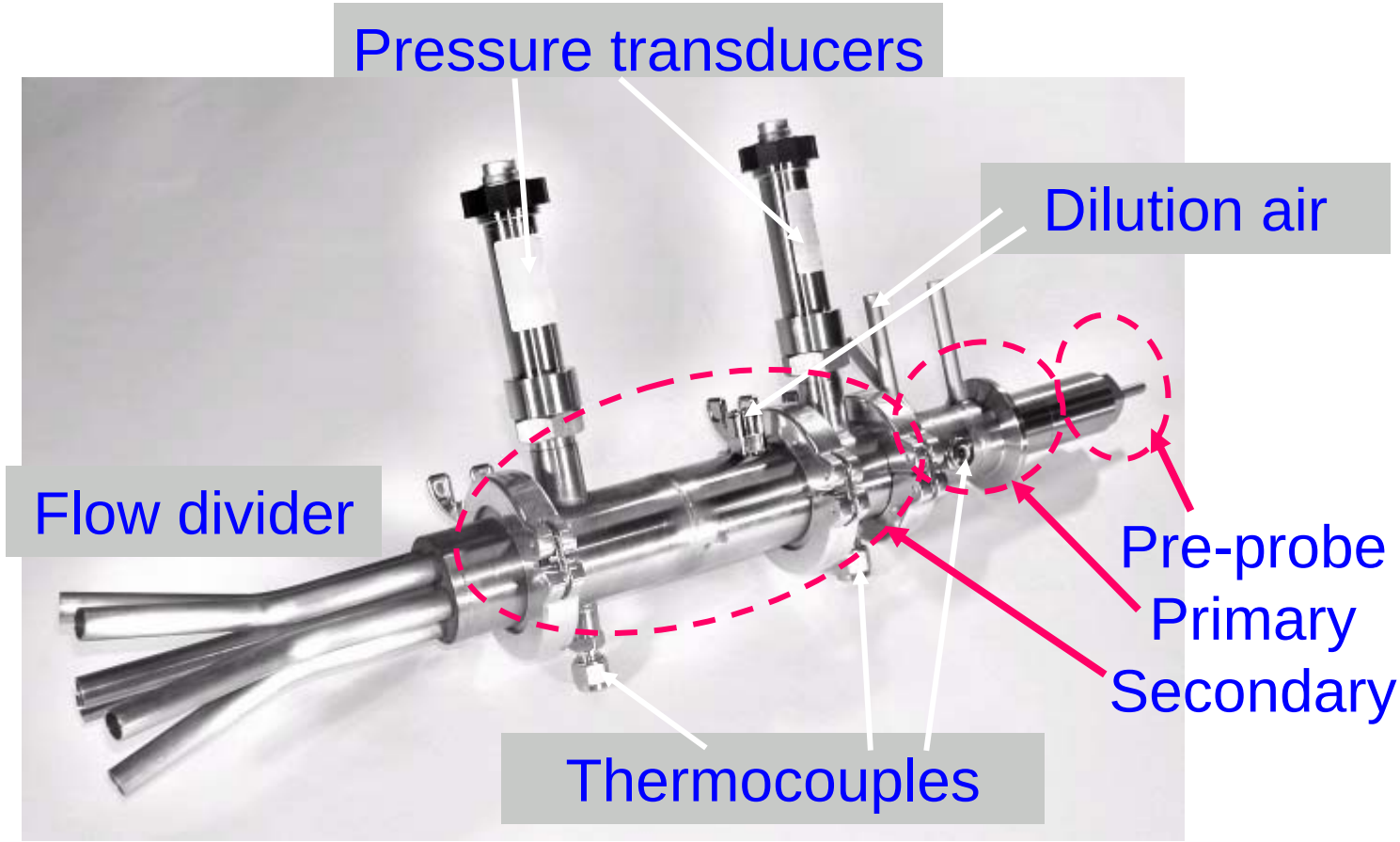
* *Develop a sampling, conditioning and measurement system that provides realtime dilution ratio and sub microgram mass measurement with well defined and controlled thermodynamics of the DPM sample on 1 sec basis*

HI-RES 6100
Operation Principle

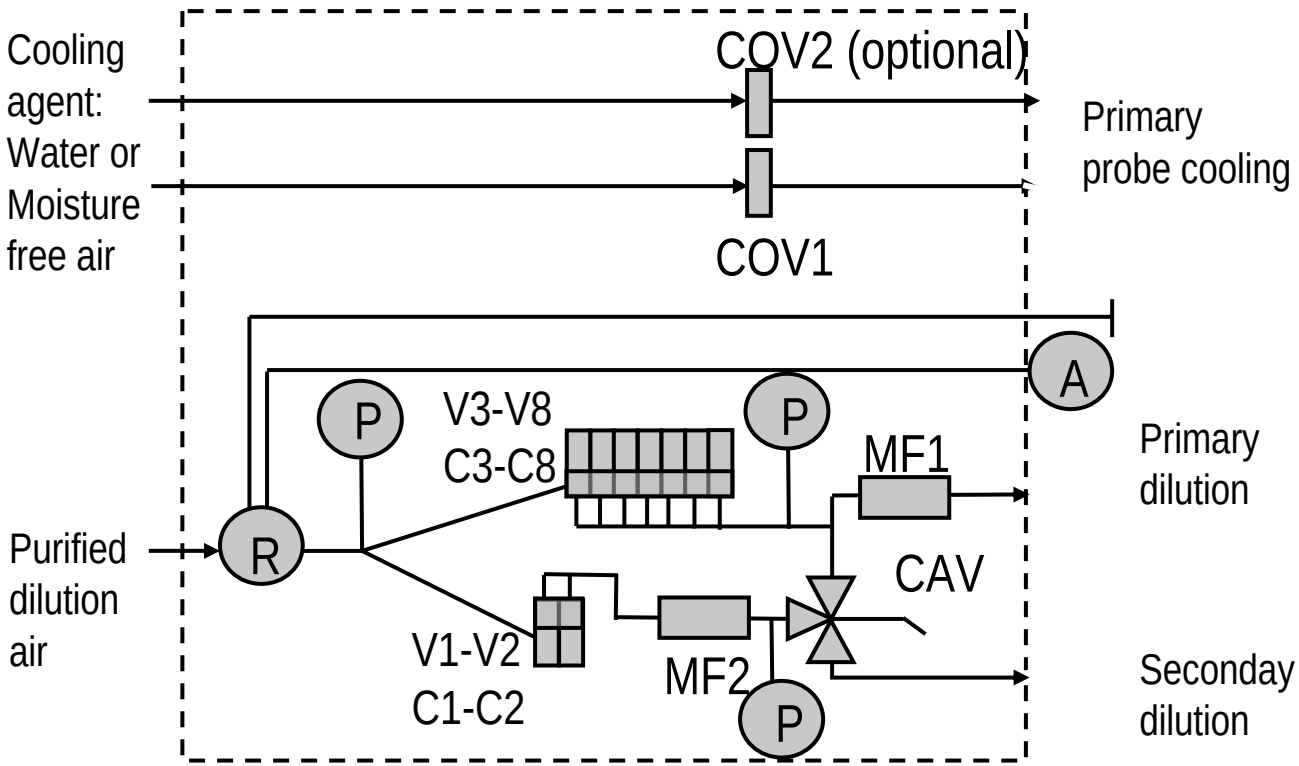
- 6100 Probe
  - *Primary dilution*
    - Porous tube dilution prevents losses
    - Cold or hot primary dilution
    - Dilution air characteristics can be modified
    - Controlled dilution ratio
  - *Secondary dilution*
    - Ejector type diluter acts as pump
    - Continuous monitoring of dilution ratio
    - Cooling of sample
    - ➢Provides size distribution similar to atmosphere
    - ➢Enhances or prohibits nucleation in controlled manner

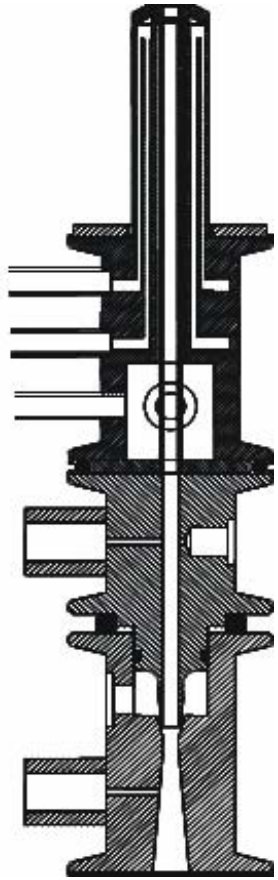


HI-RES Series 6100 Micro Diluter



HI-RES Series 6100 Flow Schematic





R Pressurised air regulator
P Pressure transmitter
Vx Valves
Cx Critical orifices

A Analog display for pressure adjustment
MFx Mass flow sensors
CAV Validation valve (manual)
COVx Proportional cooling valves

Dilution ratio calculation

1. *Calculation of individual ejector flow ($Q_{ej,in}$) as a function of ejector inlet pressure and temperature*
2. *Calculation of dilution air flows ($Q_{po,dil}$, $Q_{ej,dil}$)*
3. *Monitoring for dilution air flow rates*

$$DR_{tot} = DR_1 \cdot DR_2 = \frac{1 + \frac{Q_{ej,dil}}{Q_{ej,in}}}{1 - \frac{Q_{po,dil}}{Q_{ej,in}}}$$

- *Dilution ratio determined ±5% of measured value*
- *Dilution Ratio ranges from 5:1 to 60:1*

Series 6100 HI-RES Micro Diluter Unique Features and Applications

- Continuous dilution solution for
  - *Automotive soot measurements*
  - *Automotive soot and nucleation measurements*
- Controlled
  - *Dilution temperature – hot/cold*
  - *Nucleation tendency*
- Full Integration into 1105 Windows Software
- Integration to data logging systems
  - *Dilution ratio on 1 s basis*
  - *Dilution temperature and pressure monitored*

TEOM Monitor

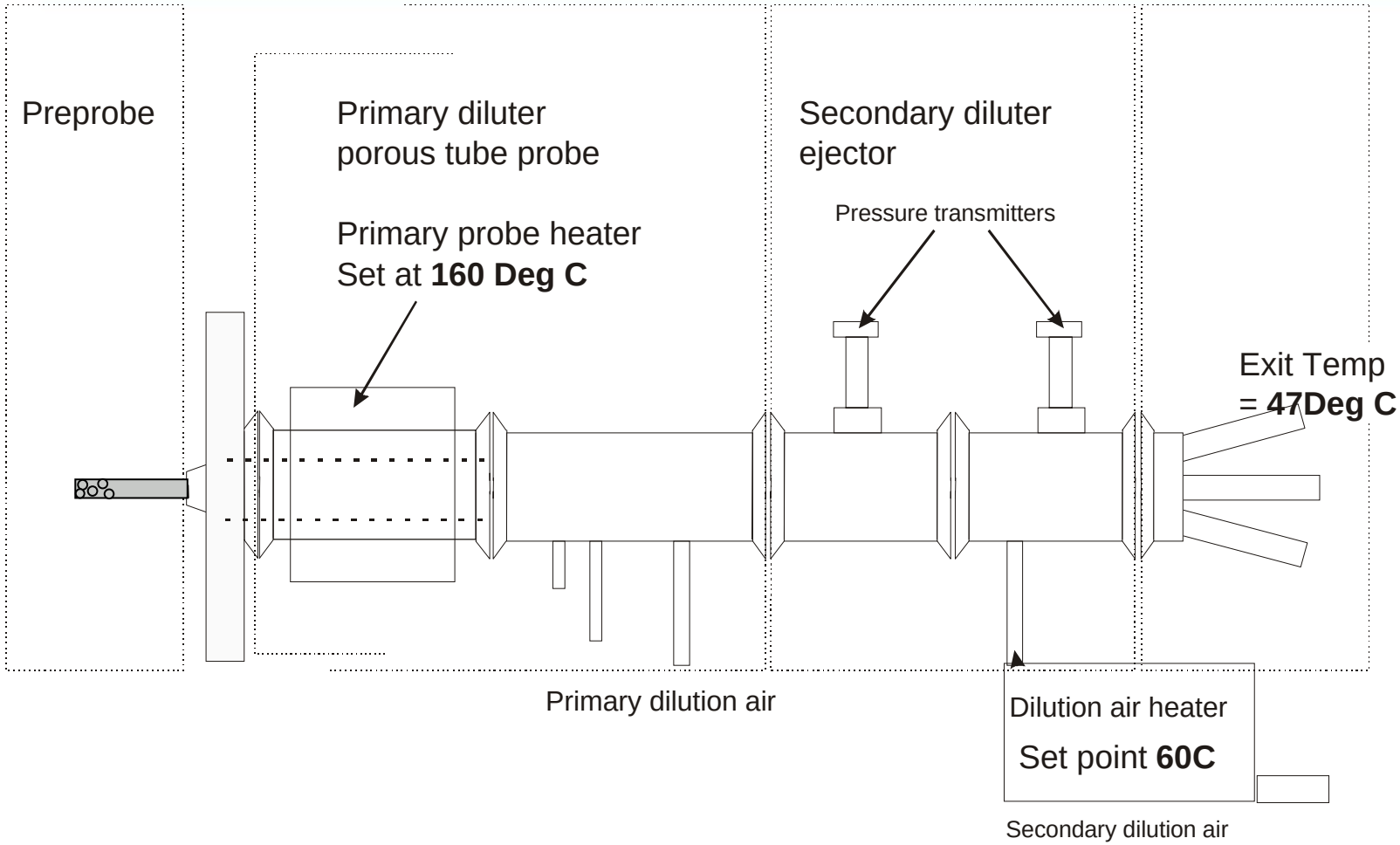
- The TEOM® Series 1105 Diesel Particulate monitor is capable of providing highly precise, near real-time, direct mass measurement of particulate matter on a filter.

$$\Delta M(g) = K_o\left(\frac{1}{f_1^{\,2}} - \frac{1}{f_o^{\,2}}\right)$$

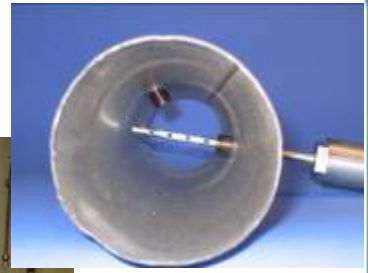
TEOM Series1105
Measurement Capabilities

- Filter-based particulate collection, paralleling reference methodologies
- Direct mass measurement of the collection filter in real time using a patented balance with 10 nanogram sensitivity (10^{-8} g)
- Total mass, mass concentration and mass rate data computed, displayed and transmitted continuously
- Quick turn-around time
- Total mass and mass conc averaging times down to one second or less

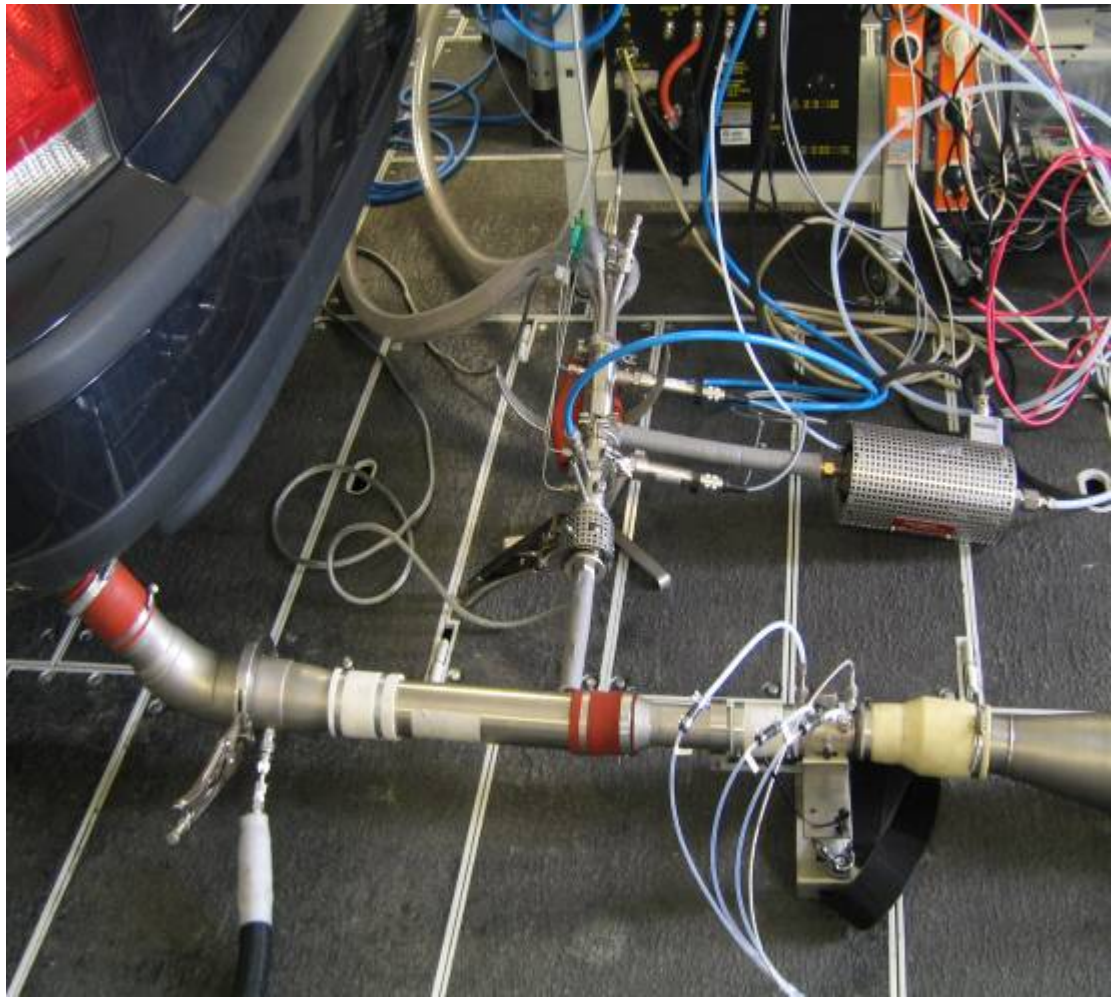
Automotive Set-up
Hot Dilution Protocol



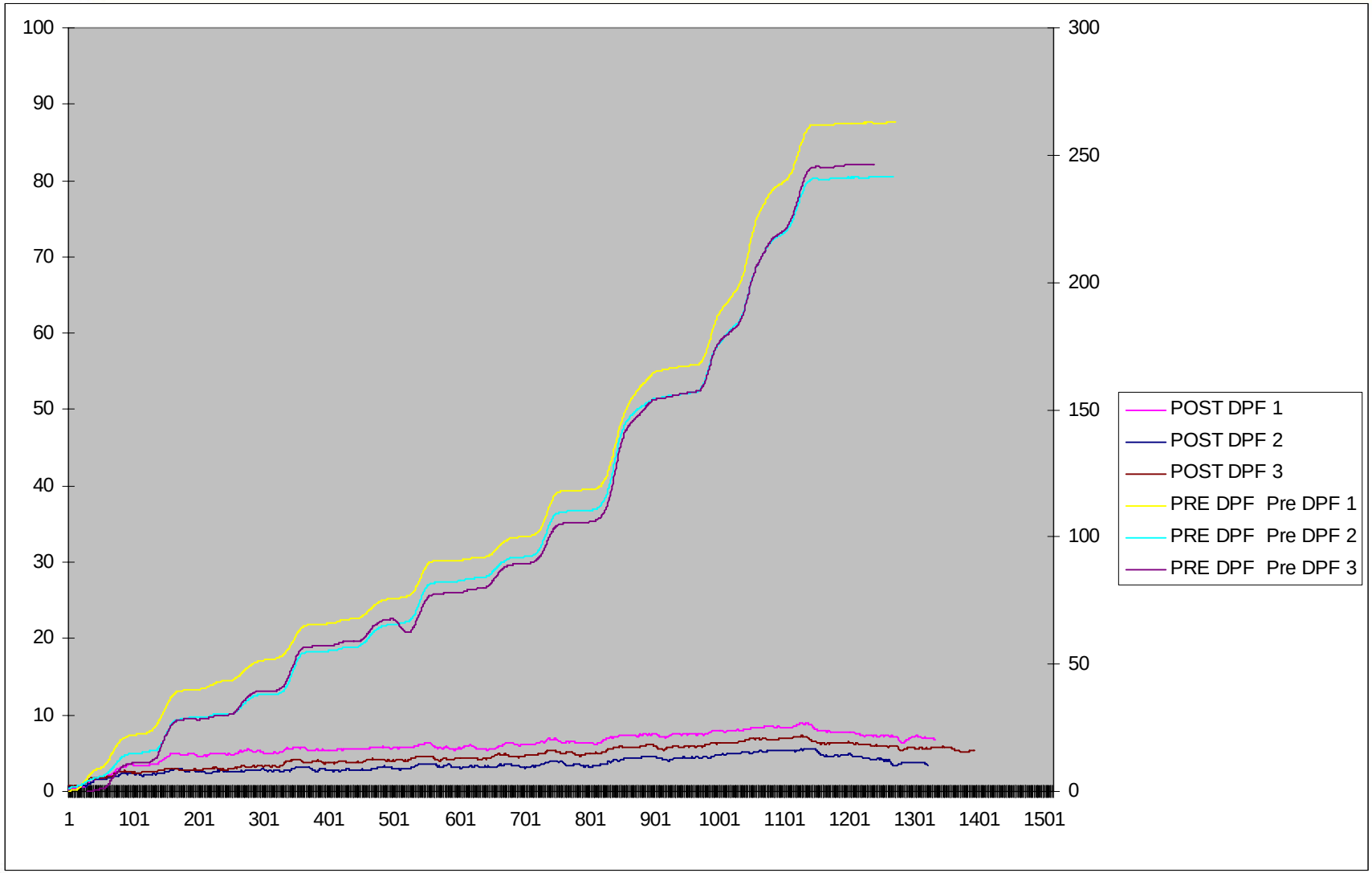
Series 6100 HI-RES Micro Diluter



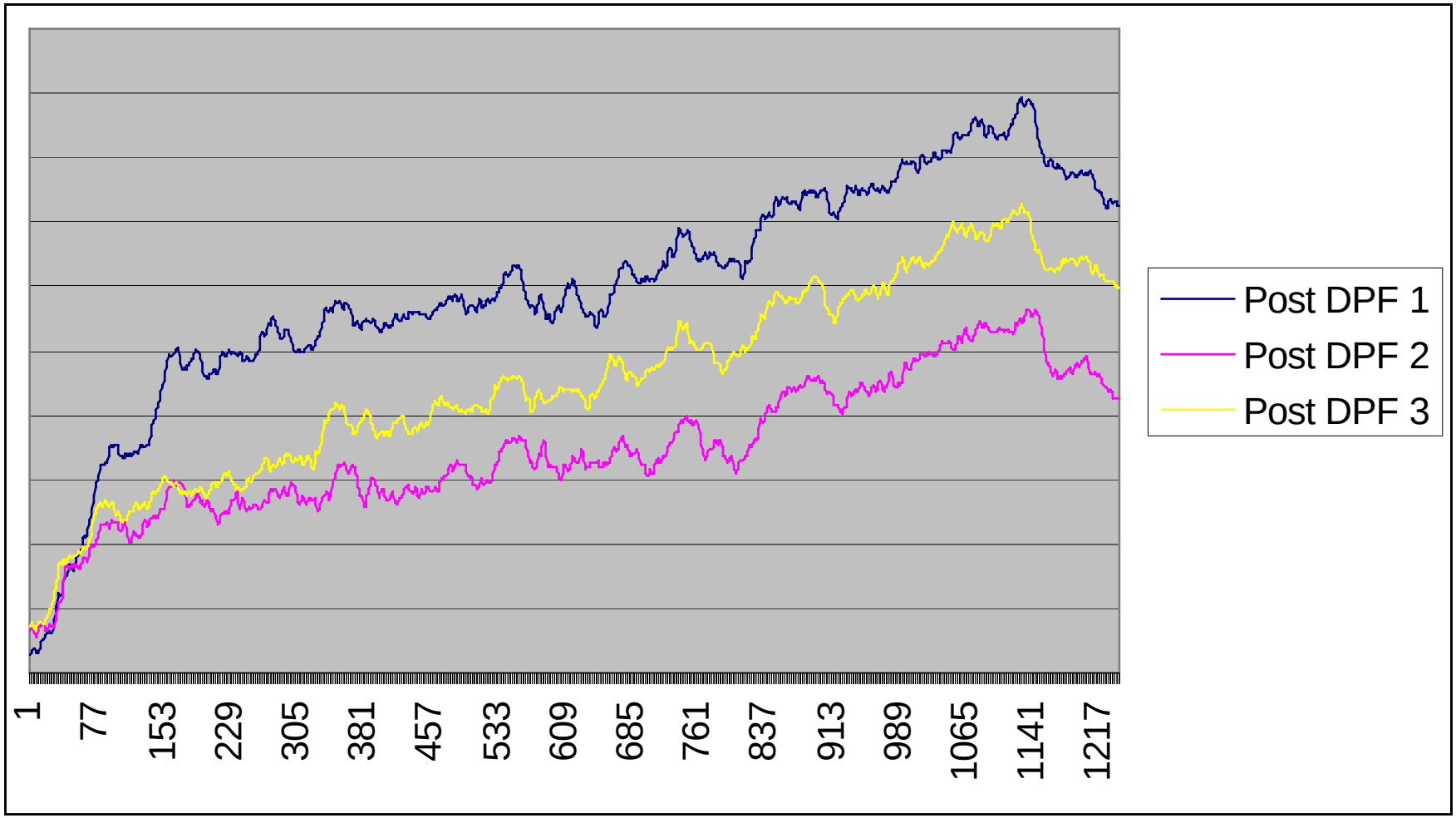
6100 HI-RES
Installation in Test Cell



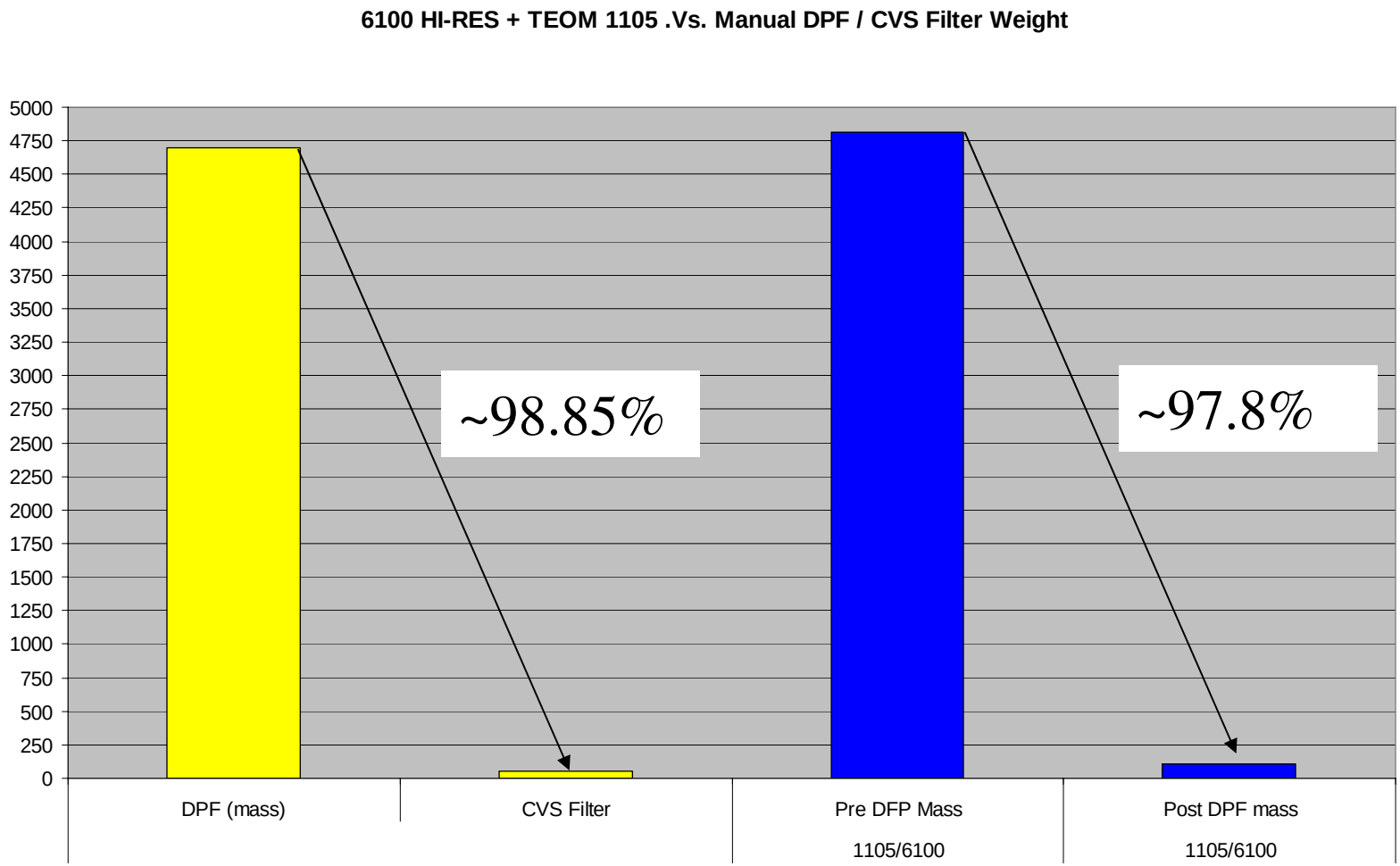
6100 HI-RES
3 Runs – Pre / Post Particulate Filter



Post DPF – 3 Runs Total Mass 1 Sec Average



6100 HI-RES + TEOM 1105 (Pre & Post) .Vs. Manual DPF / CVS Filter Weight



Conclusions

- Temperature and Pressure fluctuations in the exhaust stream are not transmitted to the TEOM in turn providing a stable aerosol to the mass detector.
- Hot-Dilution protocol minimizes water interferences and the potential for thermopheresis in the ejector nozzle
- Real-time Mass Measurements (1 sec Avg) for Pre and Post DPF can be achieved to within 10 percent or better in comparison to the manual method
- A high degree of repeatability and reproducibility can be achieved with the system
- Engine and aftertreatment benchmarking development times are significantly reduced ~ ie Higher Test cell throughput
- Post DPF Filter based PM mass measurements using inertial mass measurements are now a reality.