TEOM® Series 7000 SPM

Real-Time, Direct-Mass Source PM Measurement

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www.thermo.com/air ◆ *www.rpco.com*

Topics

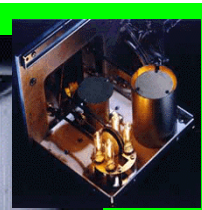
- Overview of the Series 7000 SPM
  - *The Basics*
  - *Method Validation*
- TEOM with Series 6100 HI-RES Microdiluter
  - *Configuration*
  - *OWF Application*
  - *Diesel Emissions Application*
- Questions / Discussion

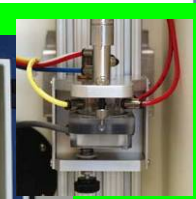
Who is Thermo EGB?

- Research and manufacturing in Albany, NY USA
- Approx. 50% of products exported
- History of rapid sales growth
- Approx 100 employees:
  - *research scientists*
  - *mechanical and electrical engineers*
  - *designers and software programmers*
  - *assembly and QA*

- Acquired by Thermo Electron April 2005; now part of Environmental Instruments Division, Air Quality Instruments

Ambient Air Monitoring Products





Thermo EGB
Emissions Monitoring Products

TEOM® Series 4200
Combustion Efficiency Monitor

TEOM® Series 1105
Diesel Particulate Monitor

Series 6186 FRM
Exhaust Filter Holder
System

TEOM® Series 7000
Source Particulate Monitor

TEOM® Series 6100
HI-RES Micro Diluter

TEOM Series 7000 SPM
Overview / Comparison to Manual Methods

- Like traditional stack particulate sampling methods, the TEOM monitor
  - *Determines the flue velocity,*
  - *Collects particles isokinetically on a filter,*
  - *Performs a direct PM mass measurement.*
- Differences from traditional method
  - *Does not requires laboratory conditioning of filters*
  - *Single-stage sampling and analysis* at the stack
  - *Completely automatic isokinetic sampling and data recording*
  - *Real-time results*
  - *Superior precision and accuracy*
  - *Demonstrated agreement with reference methods*
  - *Very high resolution (LOD ~ 100-200 $\mu g/m^3$)*
  - *Completely automated reporting*

TEOM SPM is an instrumental method incorporating requirements of Methods 1, 2, 3a, 4 and 5/17 in a rugged, portable configuration.

TEOM Series 7000 SPM
Operating Range Specifications

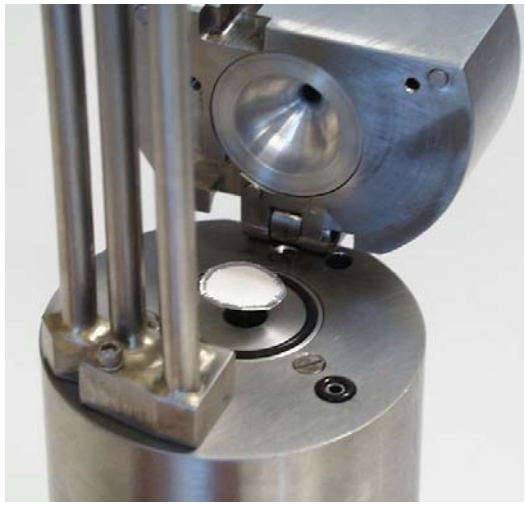
- Resolution:
  - *0.2 mg/m³ (1σ) at 120 sec MC averaging*
- Operating Range:
  - *Flue temperatures up to 200 °C*
  - *Flue velocity up to 27 m/sec (90 ft/sec)*
  - *Flue gas up to saturation; gas with droplets requires operating mode with pre- and post-conditioning*
  - *Stack radius up to 5.4 m (US), 3.2 m (Europe)*
  - *Sampling time dependent on concentration – can operate up to an hour at concentrations averaging 400 mg/m³.*
- Ambient Temperature Range:
  - *-30°C to +50°C*

Mass Measurement
Tapered Element - Theory of Operation

- Tapered element is hollow tube
- Tapered element oscillates at its natural frequency
- Particulate matter collects on filter as sample stream passes through
- Frequency decreases with accumulation of mass
- *Direct* relationship between mass and frequency change

Tapered Element

Mass Transducer Assembly



Mass Measurement Principle

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

- Calibration constant, K_o, relates changes in natural frequency to changes in mass
- K_o can be determined empirically through the use of pre-weighed filter cartridges
- K_o does not change over time, but can be verified using a mass calibration verification kit
- TEOM mass measurement principle used in ambient, diesel and power plant instruments made by Thermo (formerly R&P)

TEOM Series 7000
Main System Components

Mass transducer at end of probe

Stack Wall

Port w/ Probe Support Mechanism

Probe
(Mass transducer on hinge)

Mass Transducer

Inlet Nozzle

Pitot / Temp. Sensor Assembly

Gas Control Unit

Gas dryer
Vol. measurement
Pressure sensors

User interface
Electronics
Flow controllers
Power supplies

Pump Unit

Sample Vacuum
&
Purge Supply
Pumps

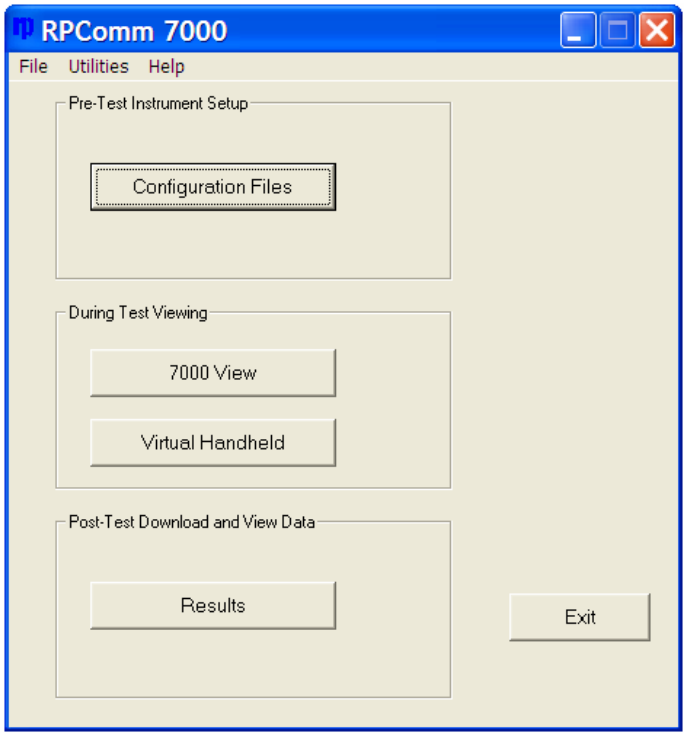
Sampling Platform

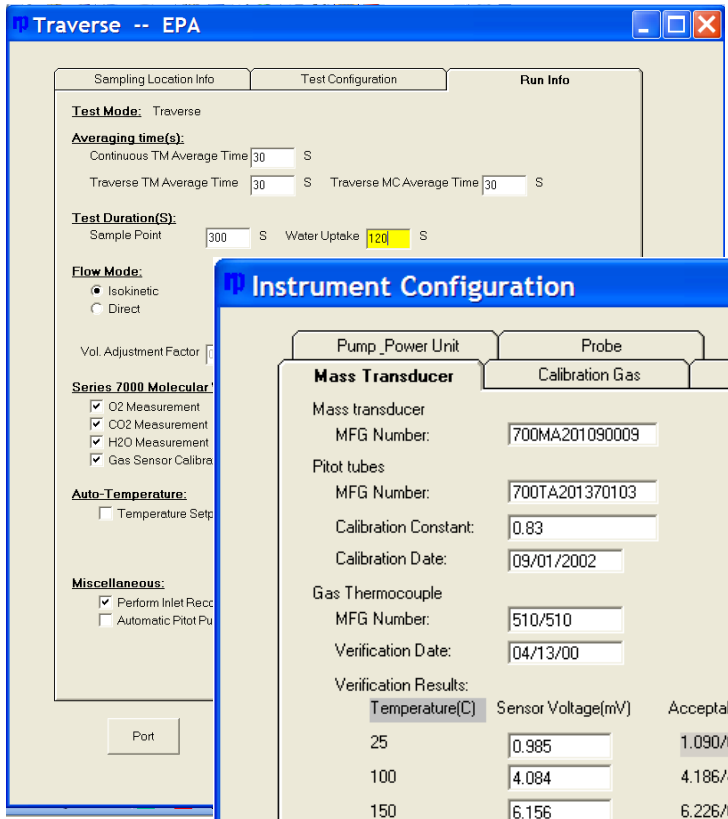
Heated Electrical / Pneumatic Umbilical
Electronic Connections
Sample Flow
Purge Flow

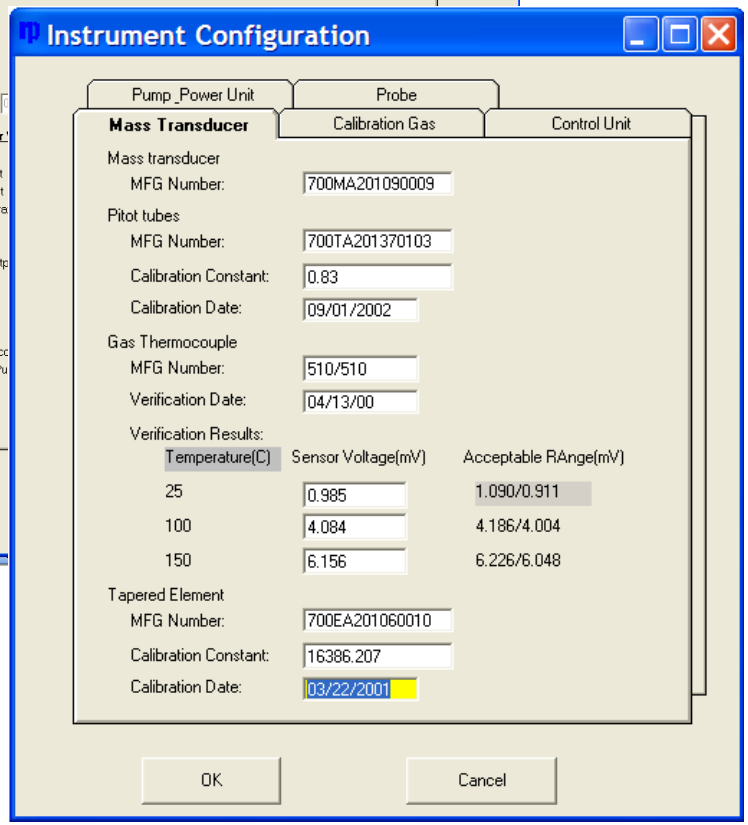
Mass transducer

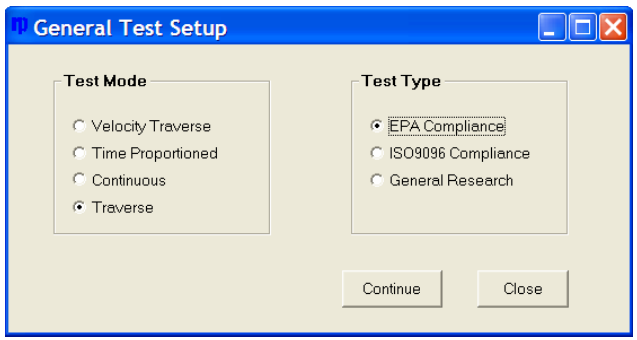
Pump and Control units

Software: RPComm7000
Standard Configuration Interfaces









Software: SPM Operating System (Accessed through Handheld Terminal Display)

```
OK  Purge  Dir
SERIES  7000  TEOM  SOURCE  MONITOR
                Main  Screen

List  of  Screens
   Perform  Test
   Set  Hardware
   Set  Storage
   Diagnostics




        Thu  Oct  12  10:21:24  2000
```

```
OK  Purge  Dir
      Perform  Test

1  Xfer  Info          9  Leak  Check
2  Test  Prelim       10  Flow  Calib
3  Leak  Chk  Pit     11  Set  Flows
4  Heater  SetuP      12  Run  Test
5  Gas  Calib         13  Inlet  Recover
6  Vel  Traverse      14  Leak  Chk
7  Inlet  Select      15  System  Bias
8  Inst  Filters      16  Storage




        Thu  Oct  12  10:21:24  2000
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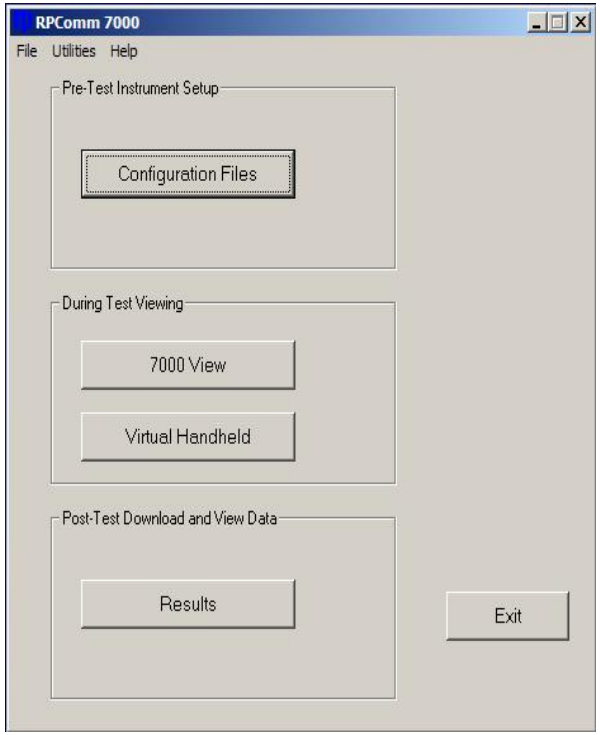
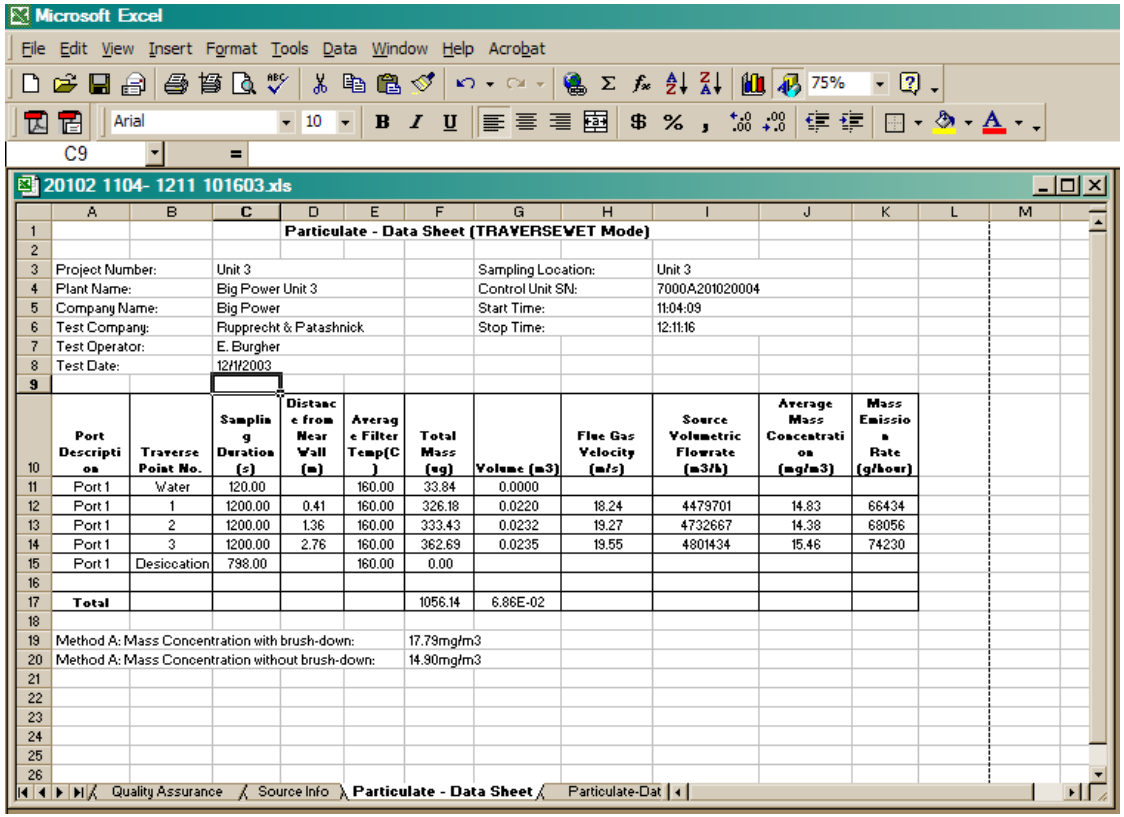
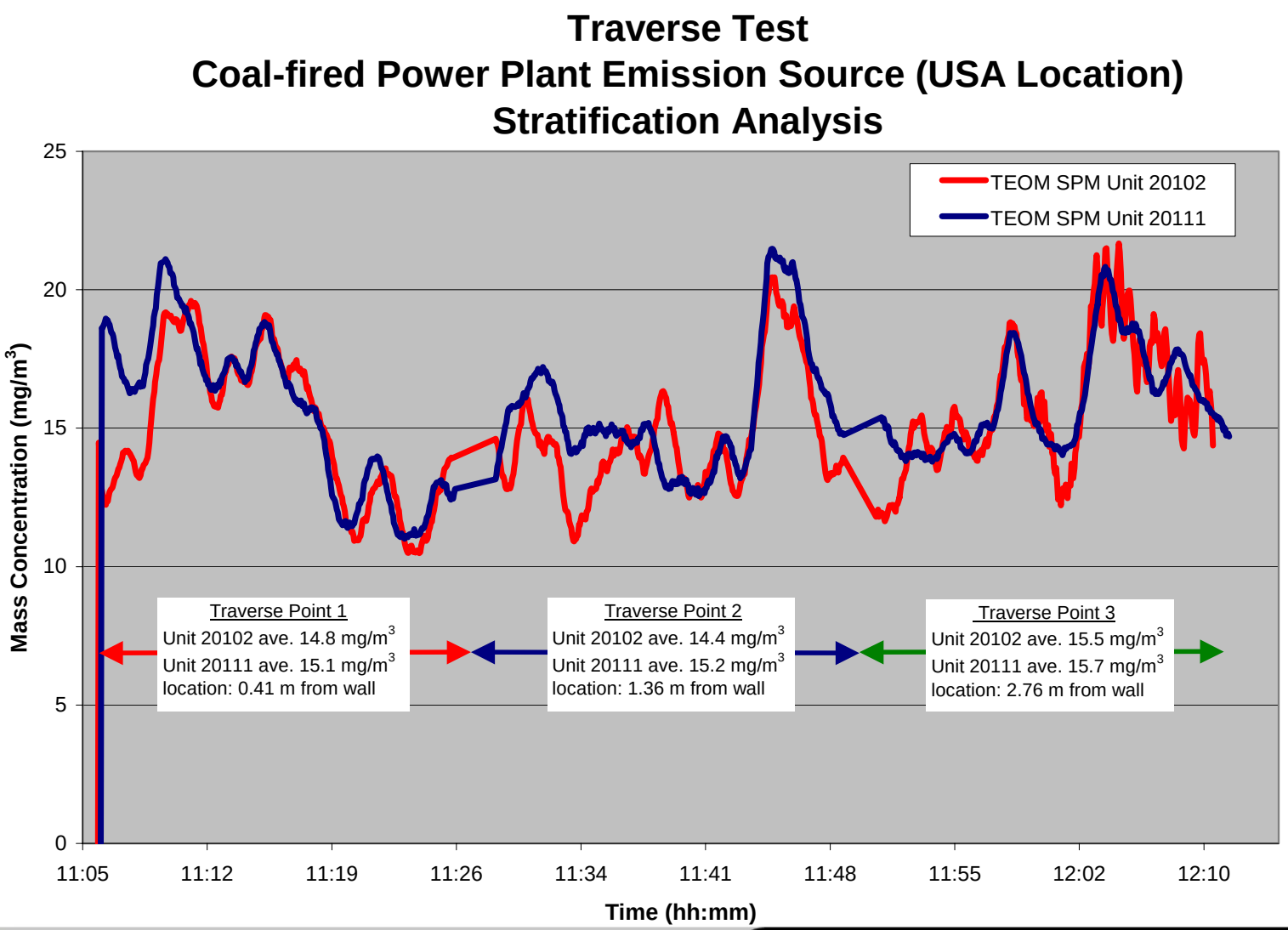
RP7000 Software: Integrated Reports Generator



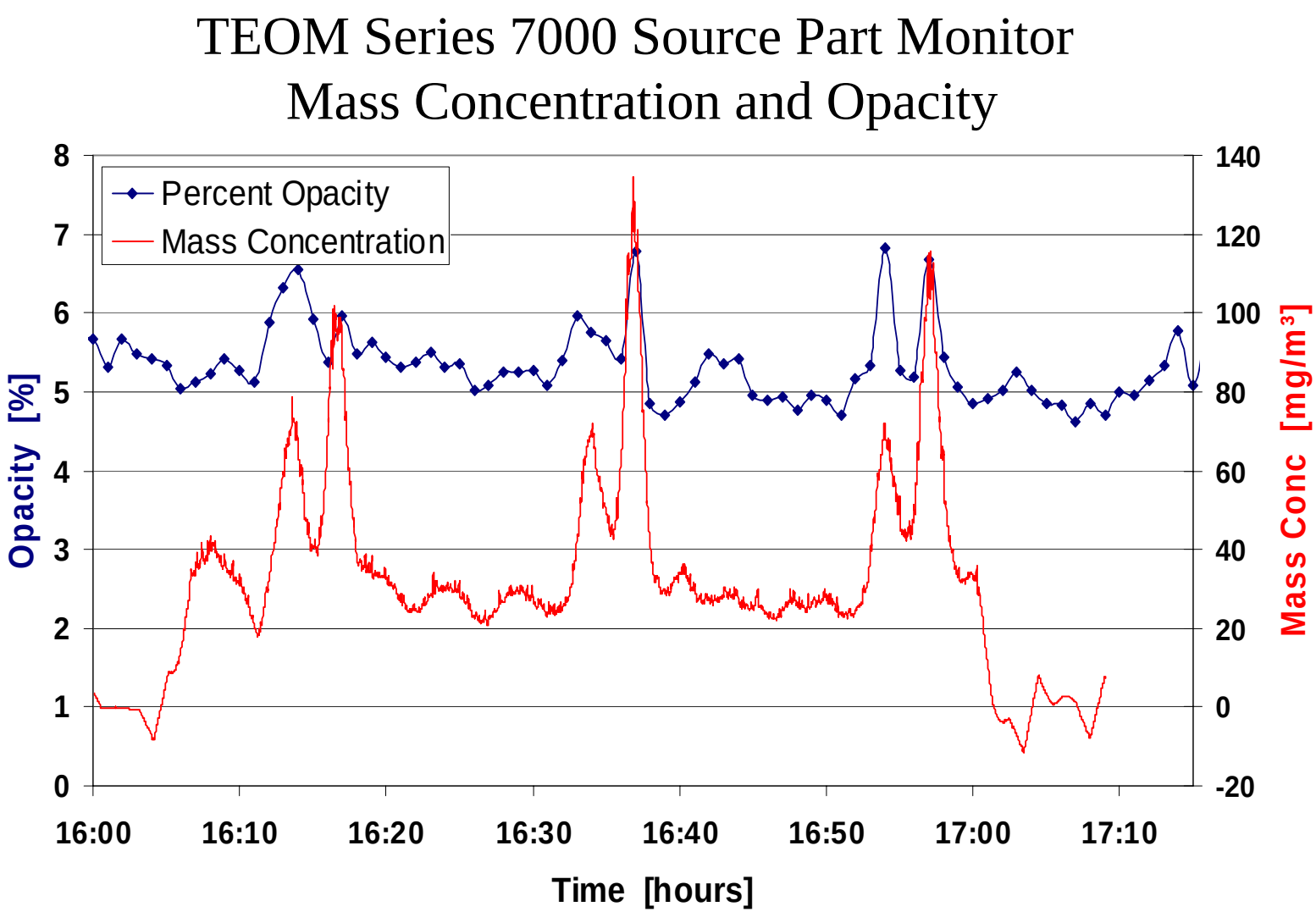


TEOM Series 7000 SPM
Measurement Examples & Method Validation

TEOM Series 7000 SPM
Stratification Test Using Traverse Mode



TEOM Series 7000 SPM Measurement Example – Continuous Mode



Summary of Methods Validation Testing

1. US: “Dry” Stacks (ESP/Fabric Filter at Coal-fired Power Plant & Coal-fired Cement Plant)
   - Series 7000 vs. Method 17
   - Series 7000 vs. Method 5
2. US: “Wet” Stacks (FGD at Coal-fired Power Plant)
   - Series 7000 vs. Method 5
3. Europe (not shown – RPCO.com website)
   - Series 7000 vs. EN 13284-1

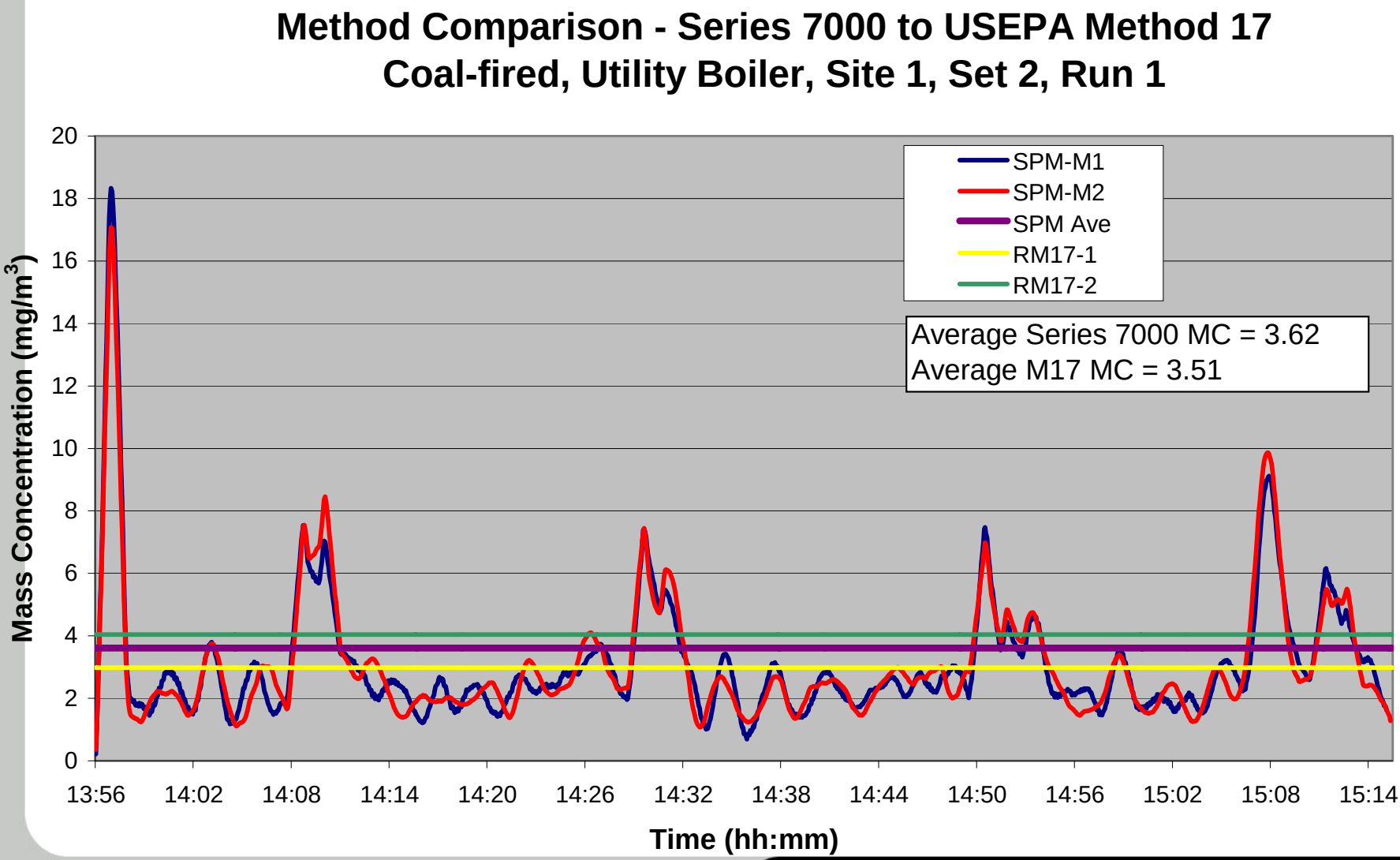
All methods validation reports and data available at:
http://www.rpco.com/products/cemprod/cem7000/index.htm

Methods Validation Test Plan Overview
U. S. Testing

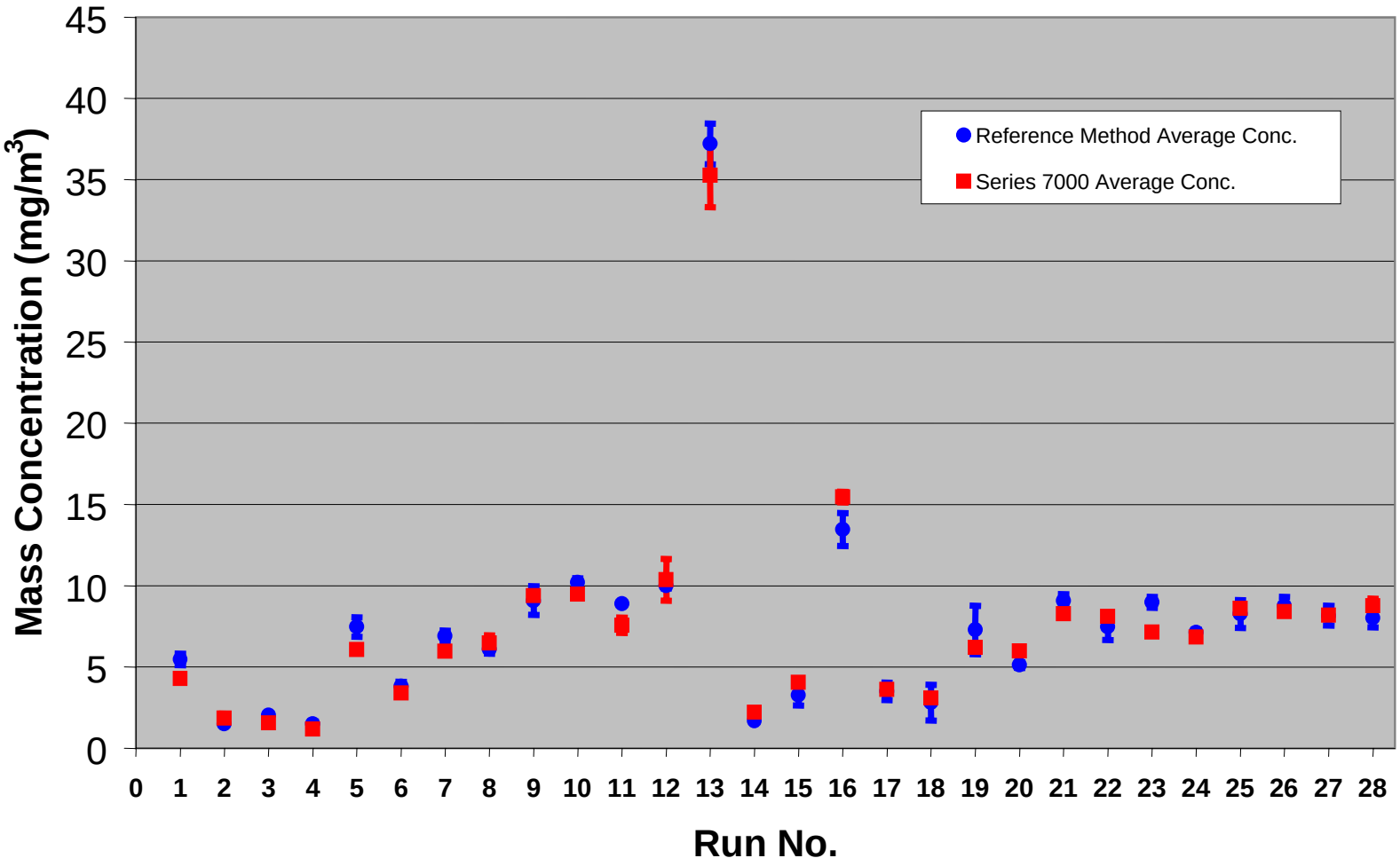
How – Follow Method 301 to:

- Compare Series 7000 Method to Method 17
- Compare Series 7000 Method to Method 5 (Front Half)
- Perform Methods Comparisons Using Quadruplet Sampling Trains (2 Series 7000 + 2 Method 5 or Method 17 Trains)
- Compare Methods in Multiple Sources, “Dry” & “Wet” Stacks
- Investigate Probe Nozzle Position Effect on Test Results
- Investigate Effect on Final Measurements of Using Series 7000’s Integrated, Real-time, Gas Sample Molecular Weight Measurement to Set Isokinetic Sampling Conditions

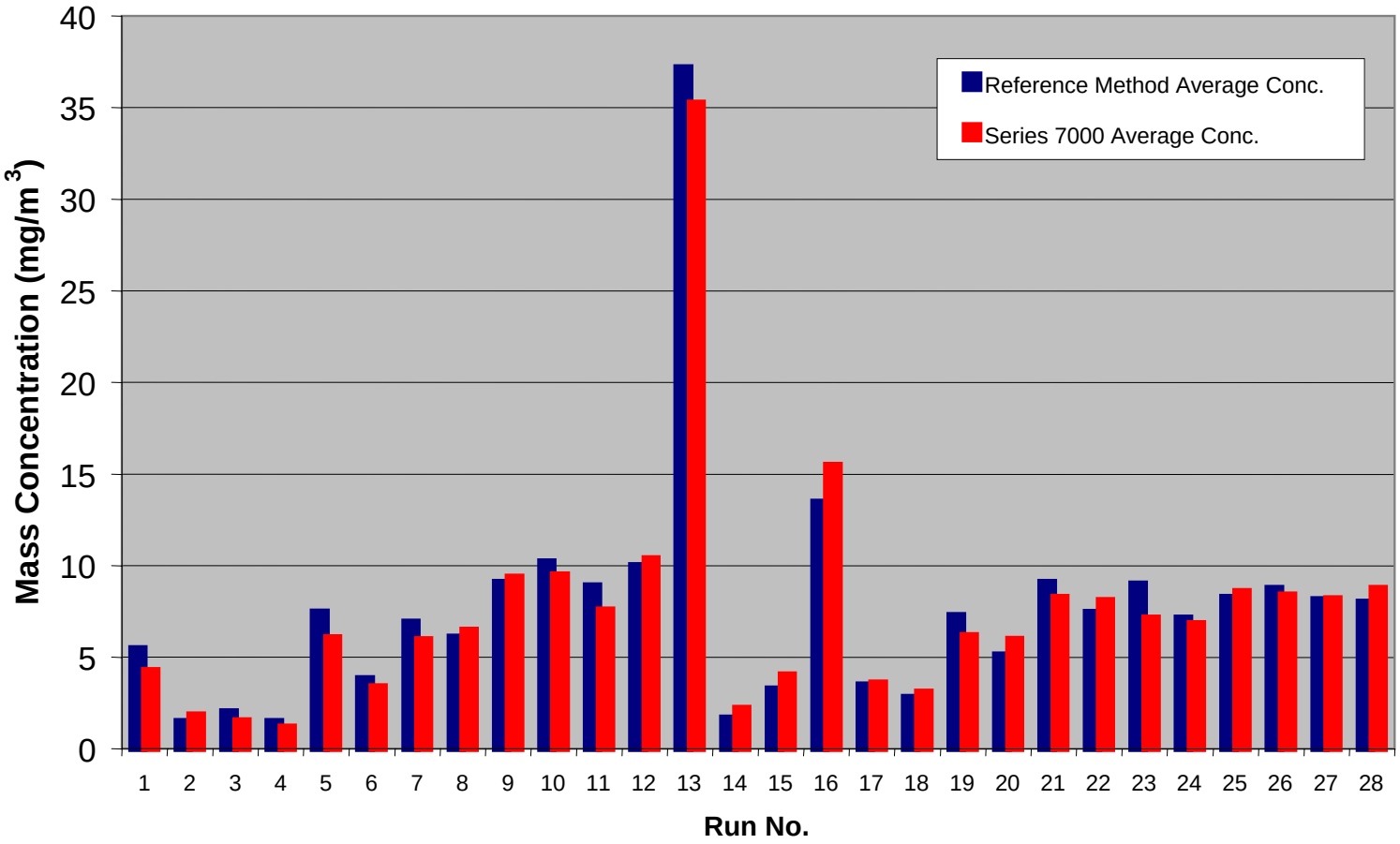
TEOM Series 7000 SPM – Method Validation Typical Test Run Results



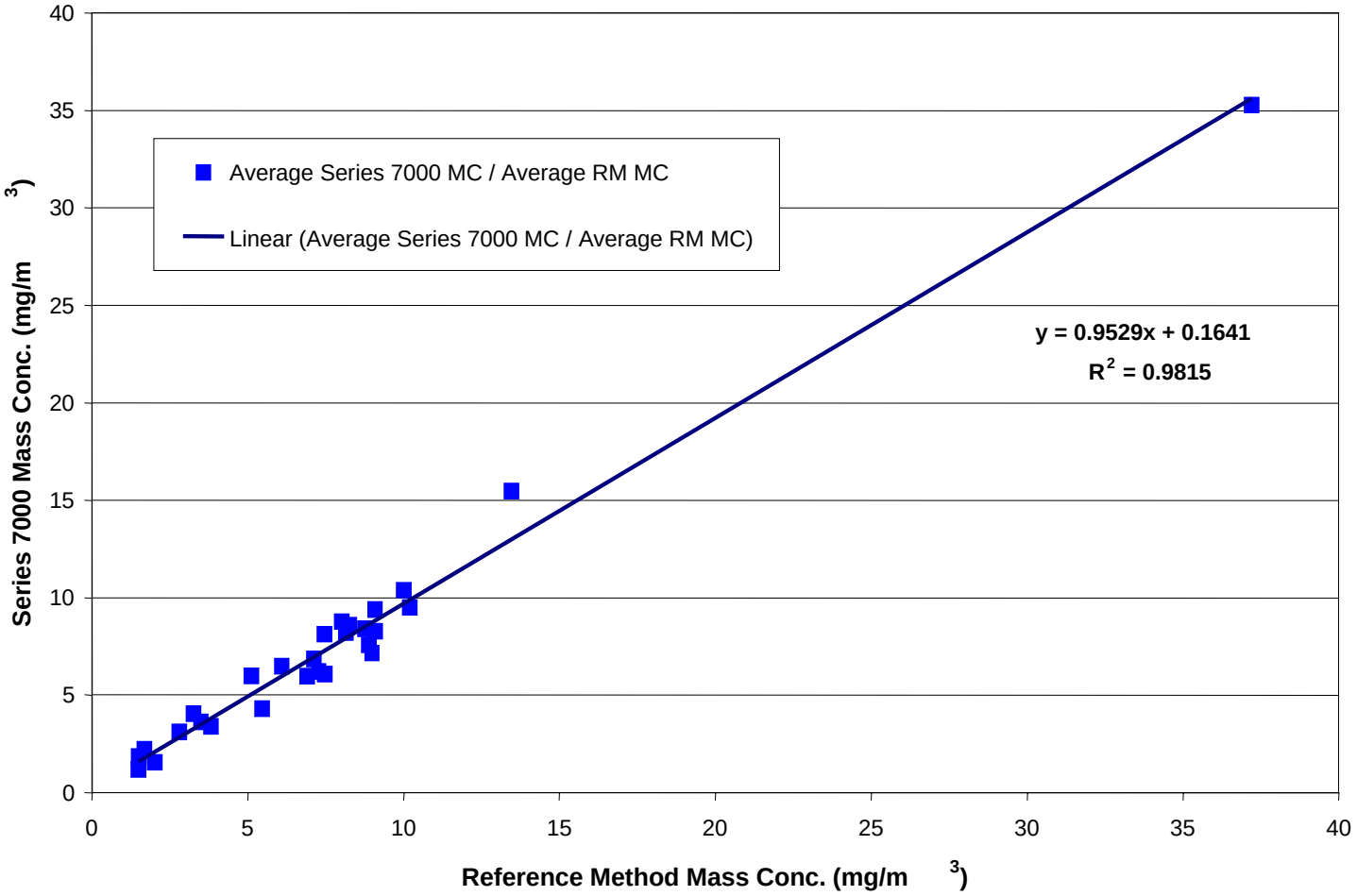
Comparison of Series 7000 to Reference Method Precision Assessment



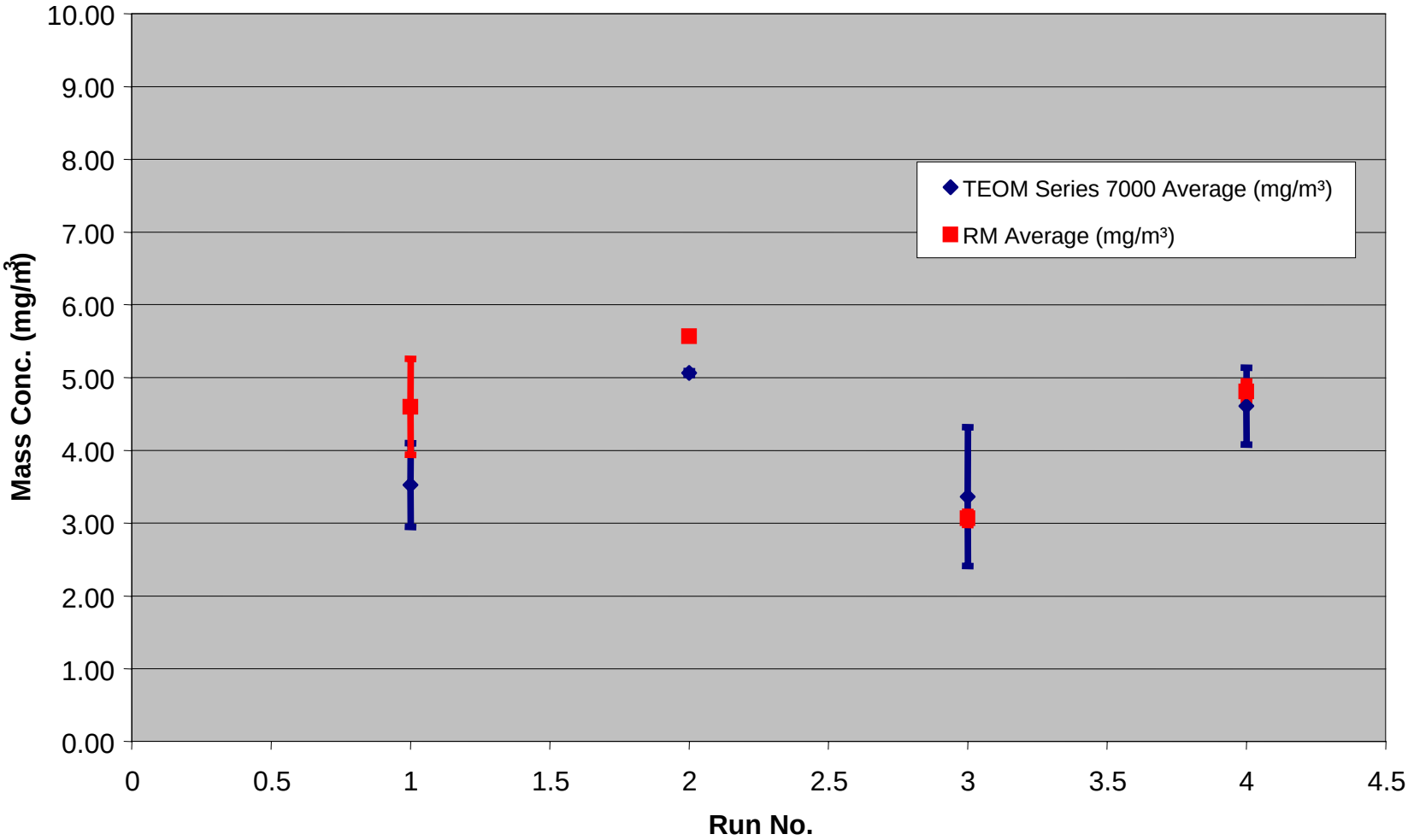
Bias Assessment - All M301 Test Results
Comparison of Series 7000 to Reference Method



Methods Comparison - Bias Assessment Average of Paired Same Method Trains



Method Validation - Precision Assessment Coal-fired Boiler: ESP/FGD Controlled



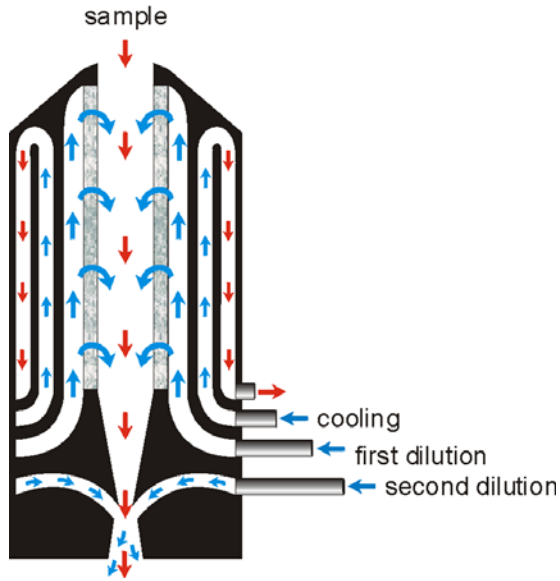
TEOM Configuration with HI-RES™ Series 6100 Micro Diluter

Micro Diluter

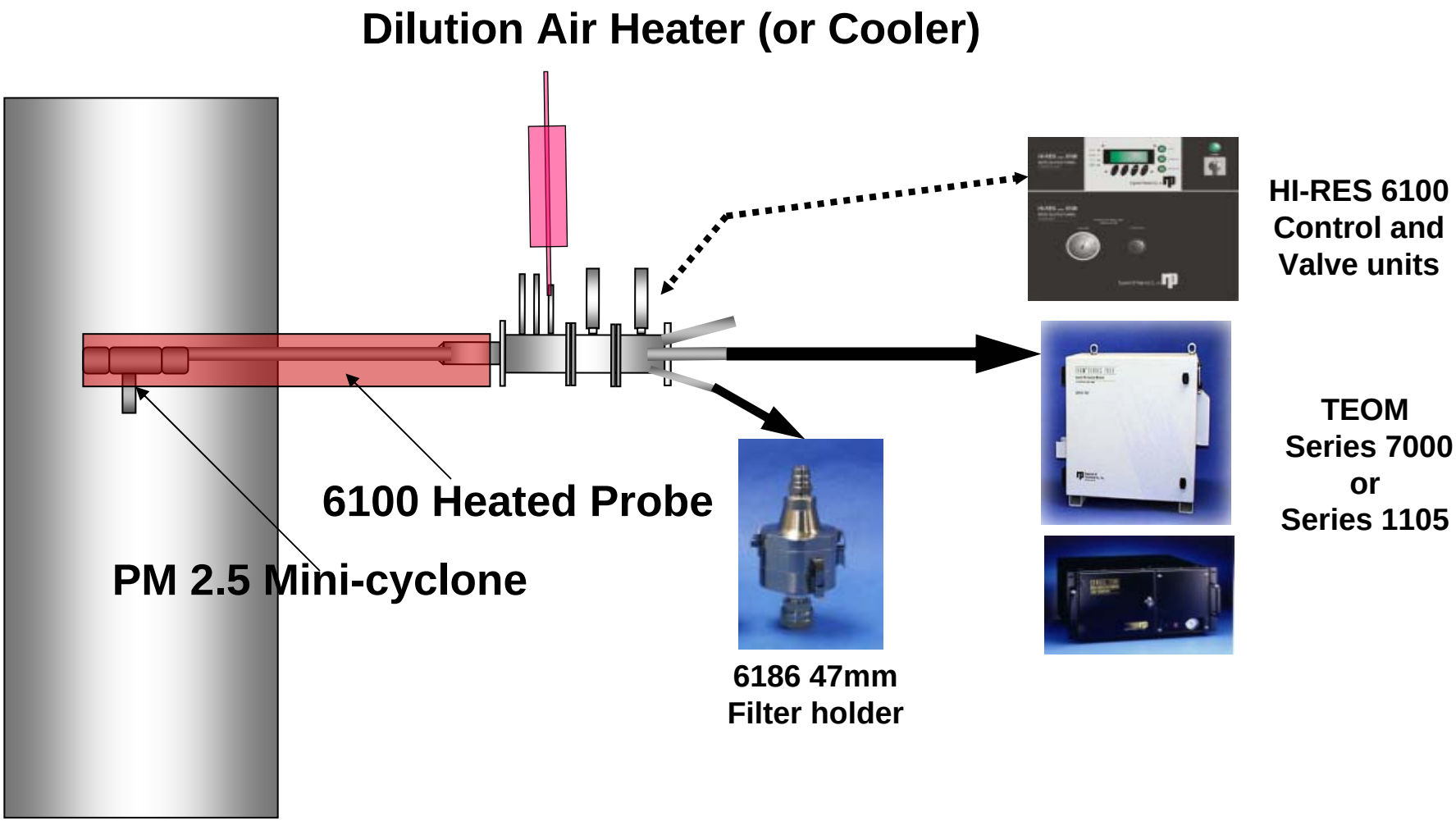
Control Interface

HI-RES 6100 Microdiluter 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
- Monitoring (temp., pressure, flow)
- Data acquisition
- User interface



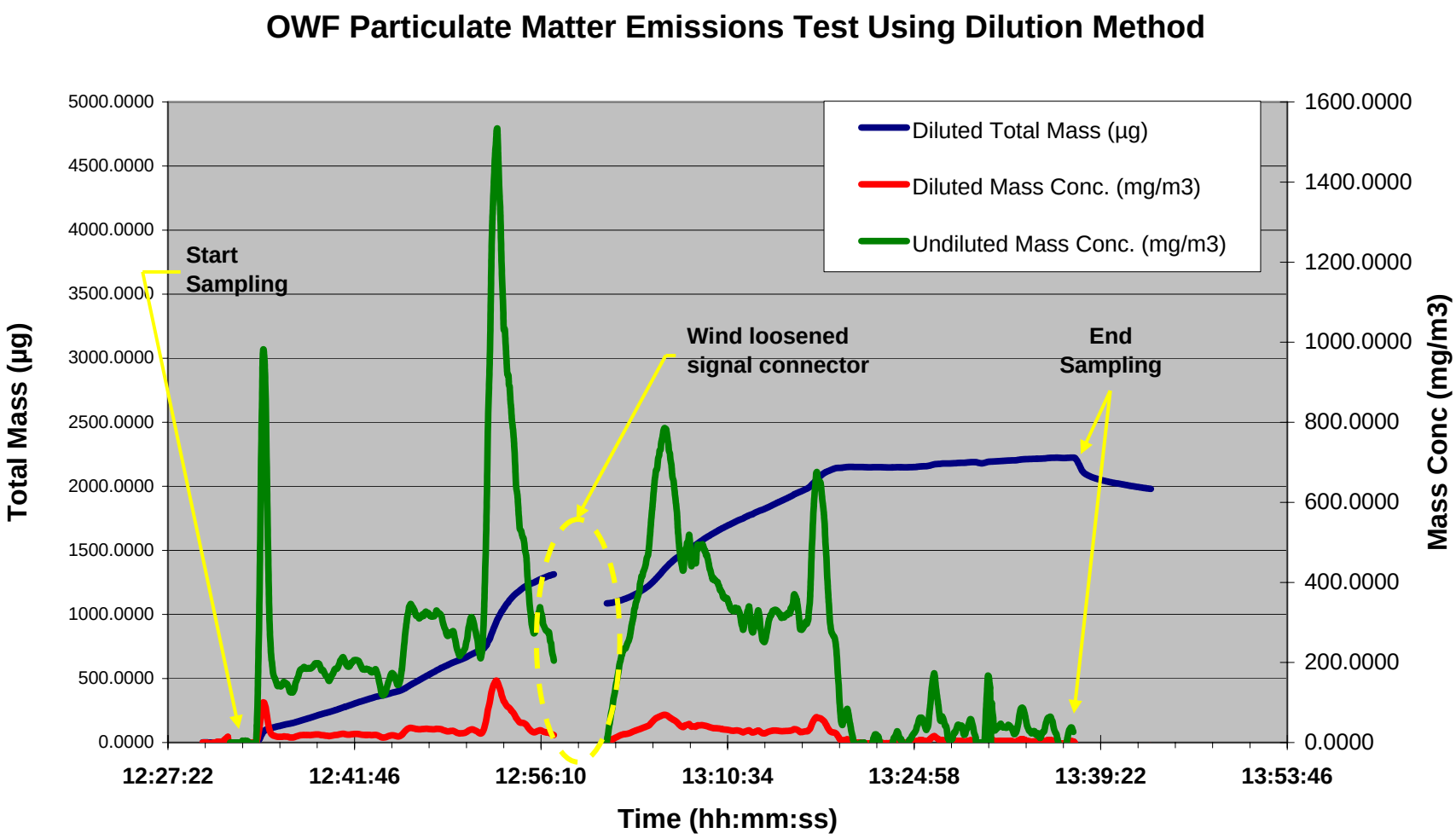
Micro Diluter Configured For PM 2.5 Stack Sampling



Microdiluter – SPM 7000 Mass Transducer Configuration for OWF Testing

- SPM 7000 Mass Transducer
- Diluter Flow Divider
- Residence Chamber
- Dilution Air Inputs
- Pressure / Temperature Sensors

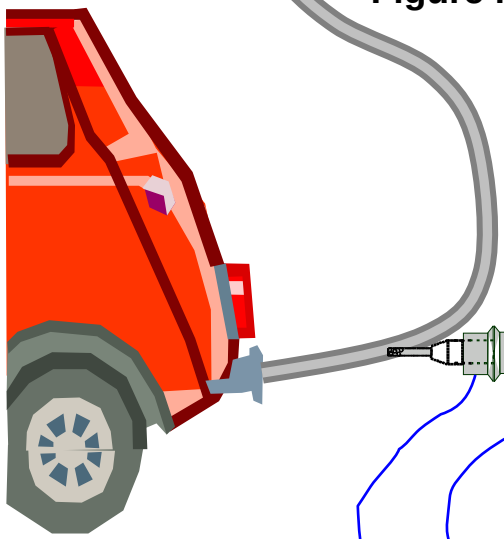
OWF Test Results
Graph of Mass Concentration / Total Mass Collected



Mobile Source / Automotive Setup

CVS tunnel

Figure not in scale



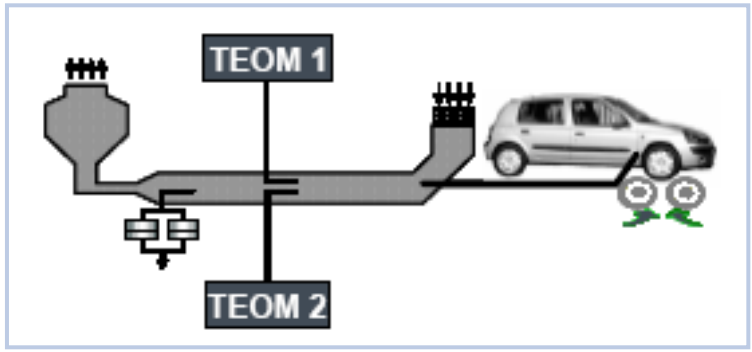
HI-RES 6100
probe

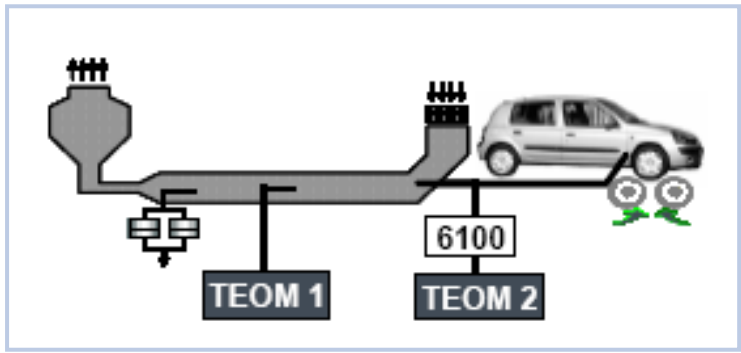
TEOM
Series 1105

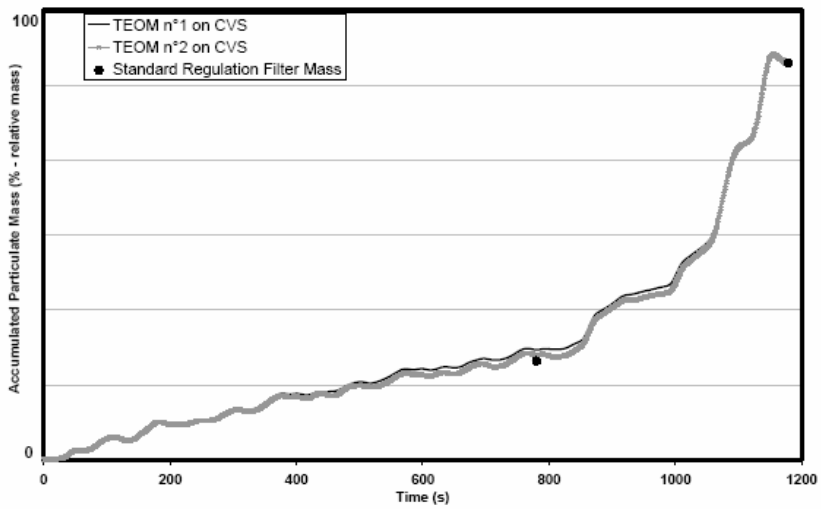
Model 6186
47mm Filter
holder

HI-RES 6100
Control and
Valve units

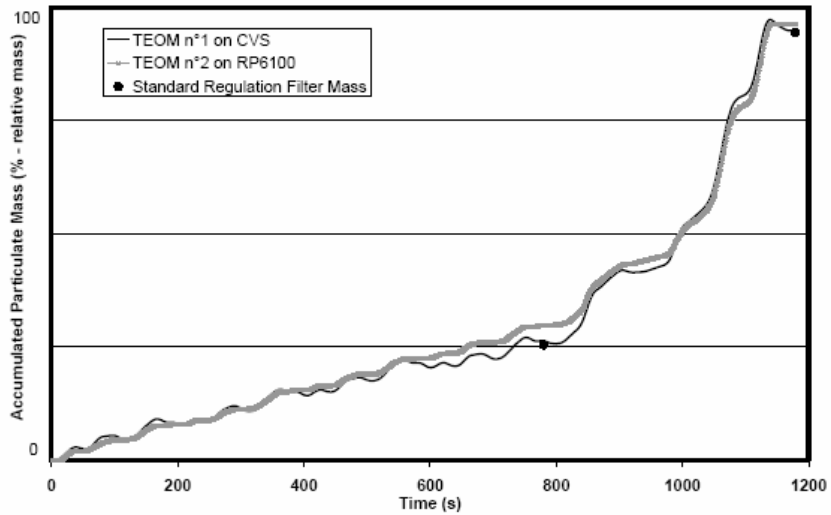
TEOM 1105 w/6100 Microdiluter Automotive Diesel Engine Application







TEOM1 (on full-flow dilution tunnel), TEOM2 (on R&P 6100 partial dilutor) and standard regulation filter total PM mass correlation, using NMVEG100 driving cycle (mg).



TEOM 1105 data reading validation. TEOM1, TEOM2 and standard filter regulation total PM mass correlation on full flow dilution tunnel, using NMVEG driving cycle (mg).

Source: Real-Time Exhaust PM Mass Measurements For DPF Development Studies, Dr. Mokhtar MAAMOURI, et. al., Renault S.A. Emission Control 2006, 18th/19th May 2006

Summary

- Series 7000 includes features, hardware and operating modes to satisfy applications such as compliance testing, PM CEMS correlation/ongoing QC, plant performance / PM emissions studies.
- Series 7000 method meets US EPA and European CEN requirements for alternative method approval.
- Series 7000 can provide higher data reliability, improved precision compared to manual methods, *with on-site results.*
- *TEOM technology can add real-time and integrated direct mass measurement capability to dilution sampling methodolgy.*

Thank you for your kind attention!