Particulate Mass Measurements from a Heavy-Duty Diesel Engine Using 2007 CVS PM Sampling Parallel to QCM and TEOM

Bruce Cantrell and Matt Spears - U.S. EPA
Imad Khalek *– SWRI

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* Presenting Author

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- David Bookers, Bookers System

Background

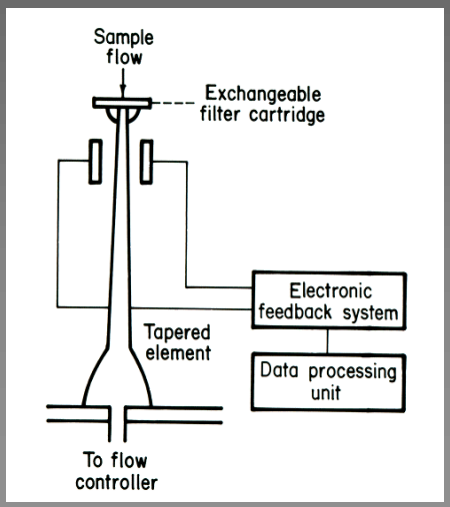
- Real Time Particulate Mass Measurement Instruments are needed for:
  - Onboard Vehicle Testing
  - Engine and Vehicle Emissions Research and Development
- Instruments Basic Requirements
  - Equivalent to US EPA 2007 Filter Method
  - Detection of very low level of particulate matter mass

Outline

- Instruments Under Consideration
  - Tapered Element Oscillating Microbalance (TEOM)
  - Quartz Crystal Microbalance (QCM)
- Evaluation and Comparison
  - EPA 2007 PM Protocol with and without Traps
    - Steady State
    - FTP Transient Cycle
    - Backhoe Loader Cycle

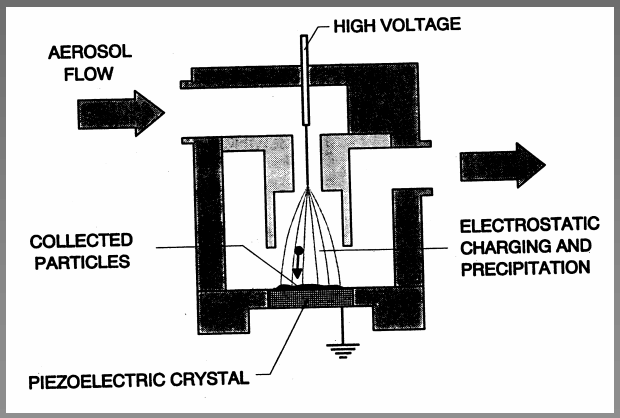
1105A TEOM Diesel Aerosol Monitor

TEOM Principle of Operation

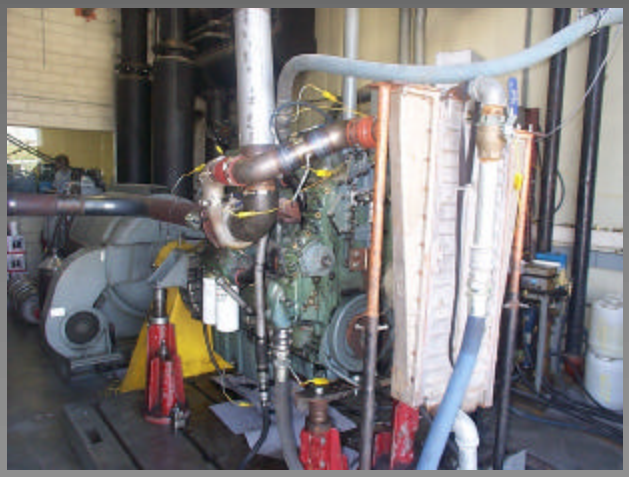


RPM – 100 QCM System

QCM Principle of Operation



1998 Detroit Diesel Series 60

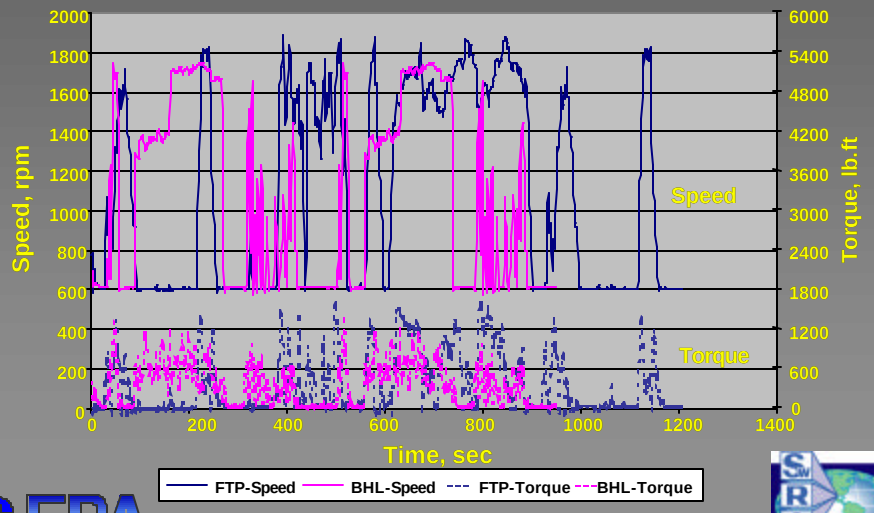


Steady State Tests
Using US 2-D Diesel Fuel

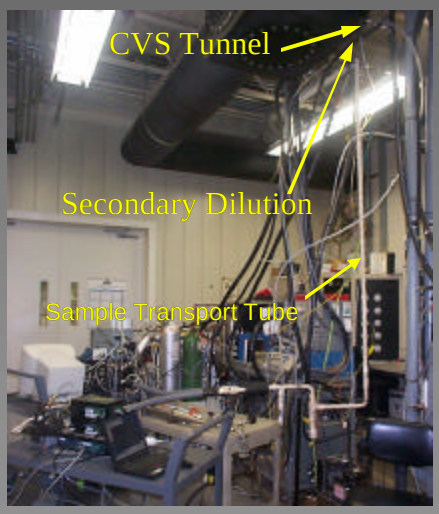
Mode	Speed	Load (%)	Sampling Time, Sec.
1	Rated	100%	600
2	Rated	50%	1500
3	Rated	25%	600
4	Low Idle	No Load	1500

Three repeats at each mode of engine operation will be performed

FTP and BHL Transient Cycles



SWRI 2007 PM Sample Configuration

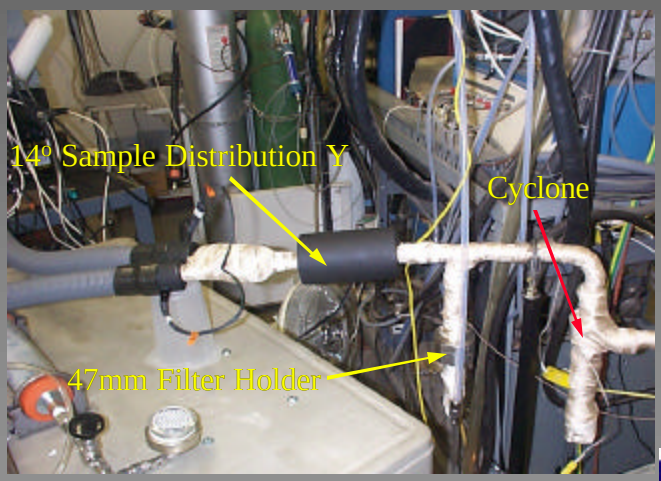


Traps Used During Tests

- Engelhard DPX
- Johnson Matthey CRT

Note: Both traps were operated using 2007 ultra-low sulfur diesel fuel, <15ppm sulfur.

CVS/Instrument PM Sample



Sample Media

- 2007 Filter Method – 47mm TX40 and Zefluor (Pall Corp.)
  - TX-40 is made of Borosilicate Micro-Glass Fibers, Glass Cloth, and Teflon
  - Zefluor is all Teflon
- Current Filter Method- 90 mm T60A20 (Pall Corp.)
  - T60A20 is made of borosilicate glass fiber and fluorocarbon
- TEOM – 13mm TX40 (Pall Corp.)
- QCM – Quartz crystal (Booker systems, Ltd.)

Instrument Sample Equilibration

- Sensor Temperature
  - TEOM = 47 °C*
  - QCM = 40 °C
- Nominal Zero Air Dew Points
  - TEOM = 33.2 °C**
  - QCM = 26.6 °C

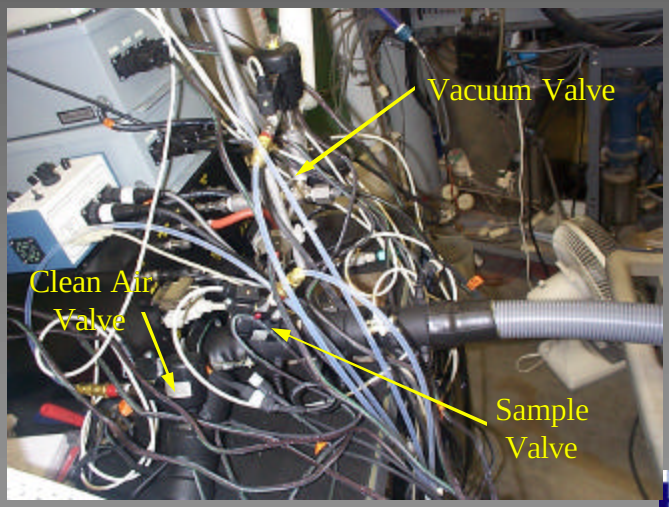
*This is consistent with 2007 Filter Face Temperature

**This is equivalent to the Weigh Room conditions of 22 °C and 9.5 °C dew point.

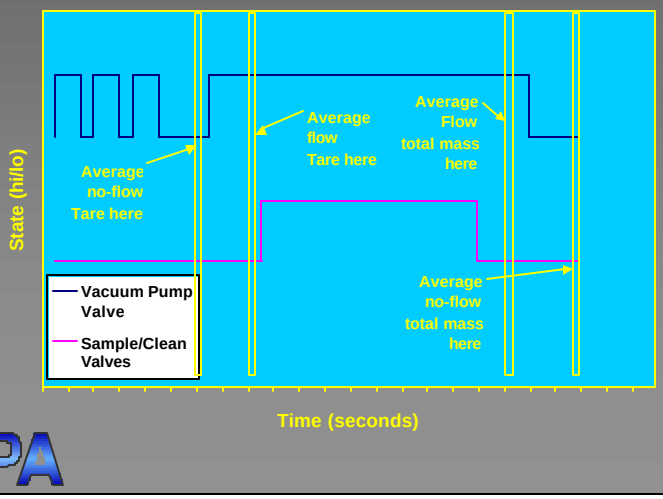
Humidification System

TEOM

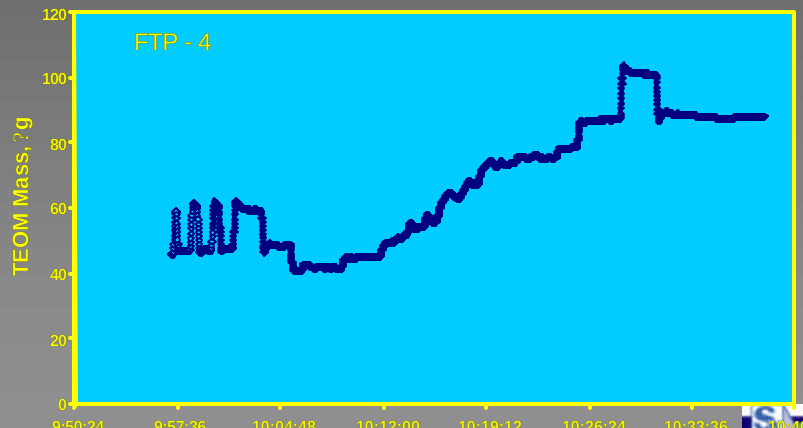
TEOM Sample Configuration



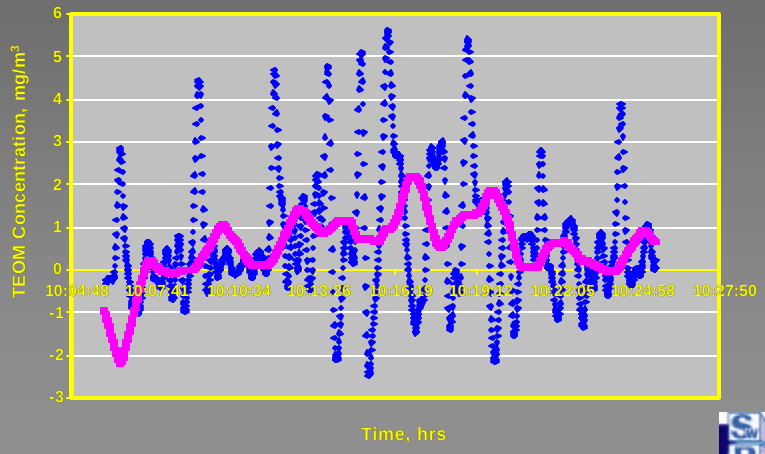
TEOM Sample Timing



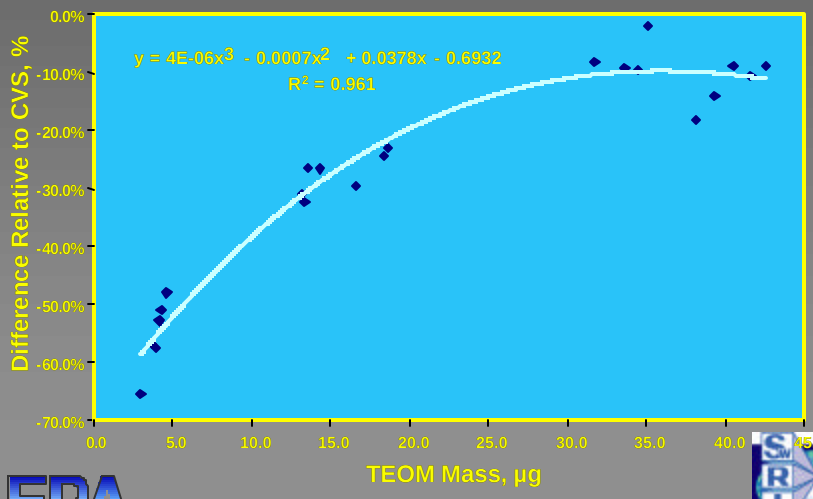
TEOM Mass for Engine Without Trap, FTP-4



TEOM Concentration for Engine Without Trap, FTP - 4

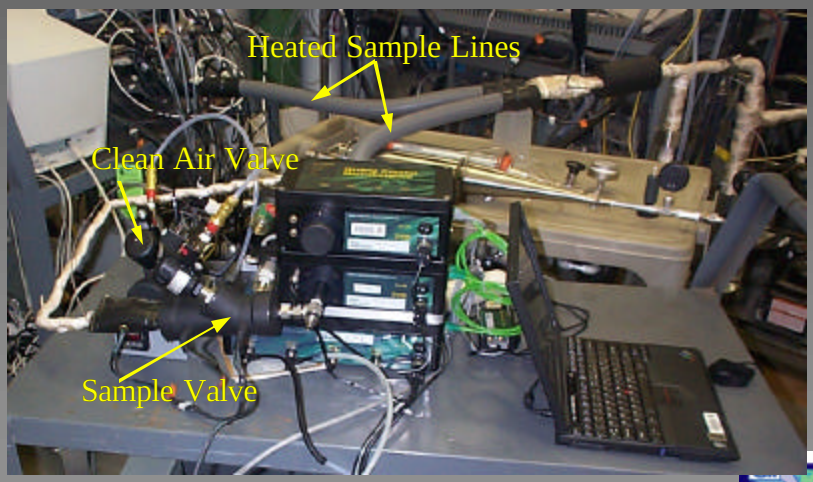


TEOM Loading Sensitivity

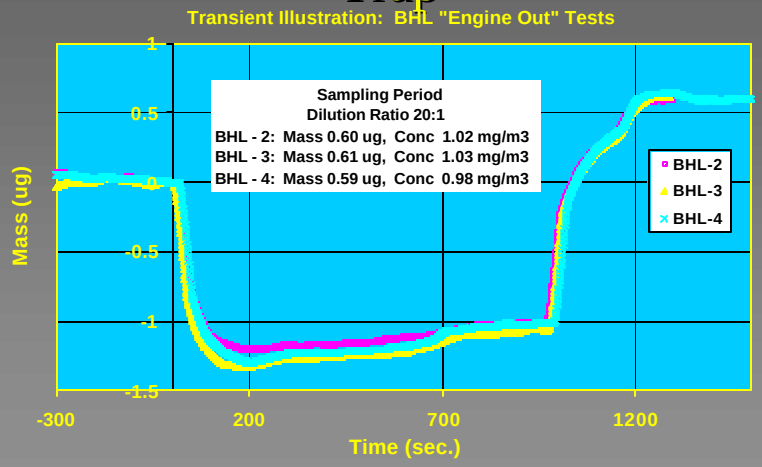


QCM

RPM-101 Sample Configuration

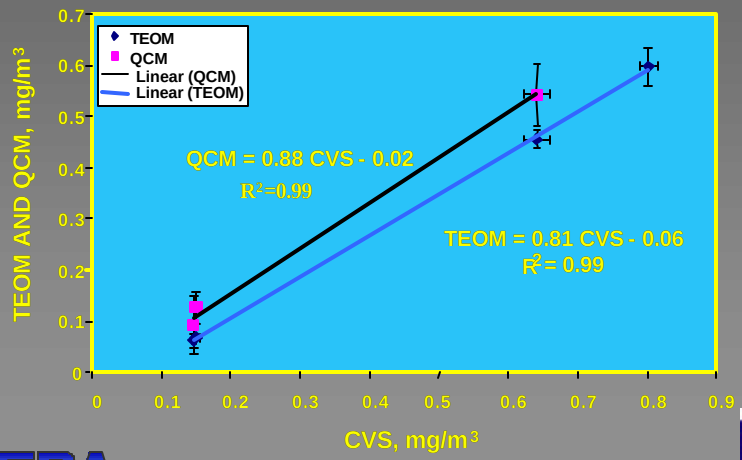


QCM Example for Engine Without Trap



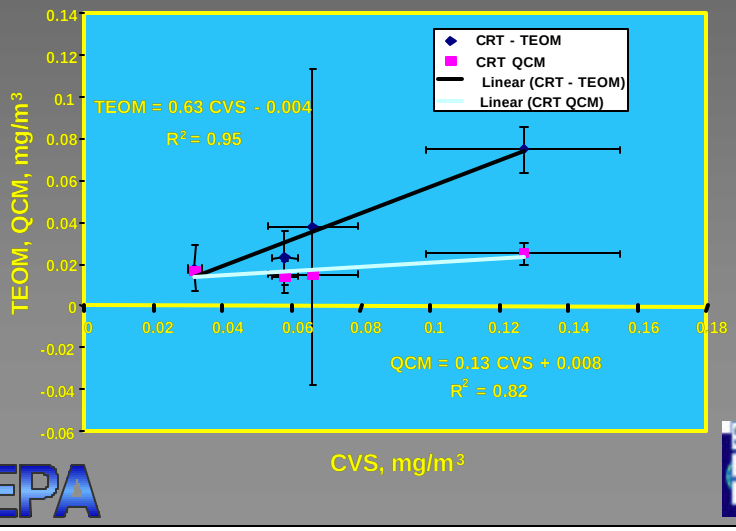
Steady State Response

Steady State Dilute Baseline Comparison Without Trap



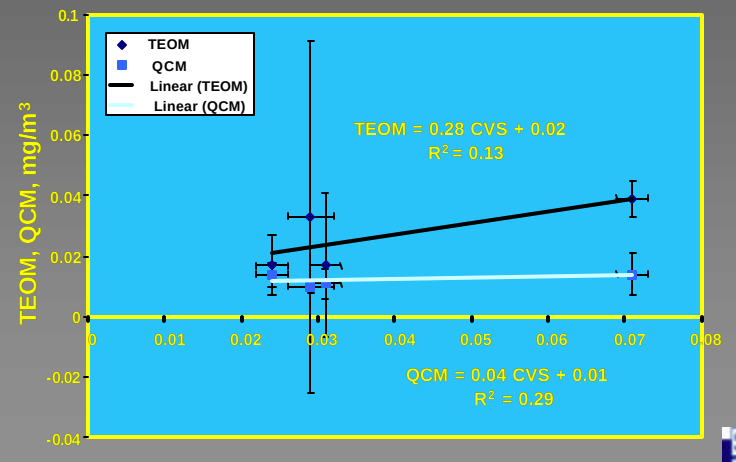
CRT Dilute Comparisons TX-40 Filter Media

(TEOM Filter Was Not Changed for Repeats Within a Mode of Engine Operation)



DPX Dilute Comparisons Using TX-40 CVS Filter Media

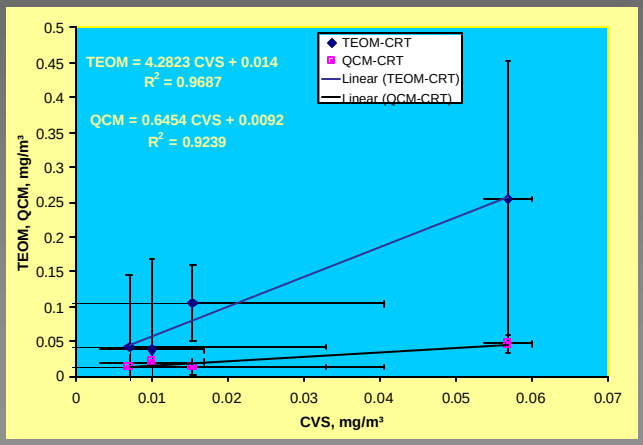
(TX-40 TEOM Filter Was Not Changed for Repeats Within a Mode of Engine Operation)



CRT Dilute Comparisons Using Zefluor CVS Filter Media

(TX-40 TEOM Filter Was Changed for Repeats Within a Mode of Engine Operation)

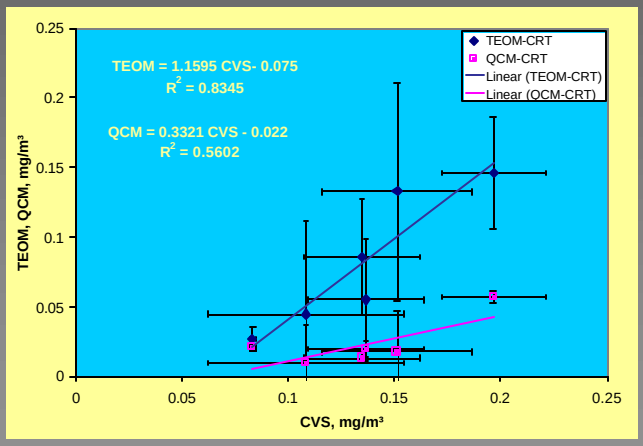
When the TEOM Used Zefluor Filters Like the CVS, the Total Mass Collected by TEOM was Negative



CRT Dilute Comparisons Using T60A20 CVS Filter Media

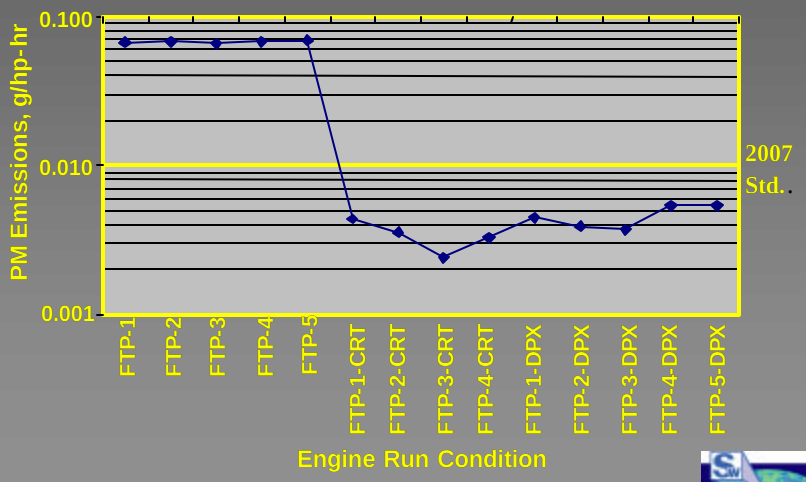
(TX-40 TEOM Filter Was Changed for Repeats Within a Mode of Engine Operation)

(Current Sampling Methodology was Used, Transient and Steady-State Data)

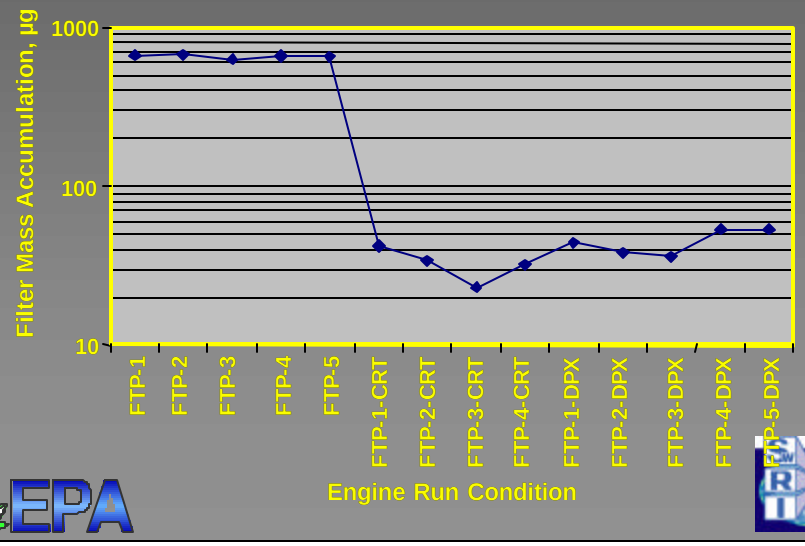


Transient Response

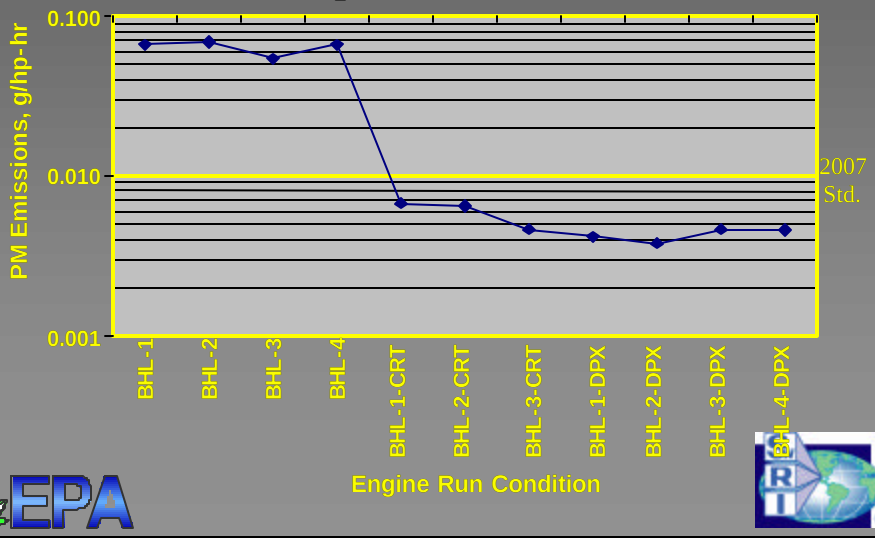
FTP PM Emissions For Engine Without and With Traps-TX-40 Filter Media



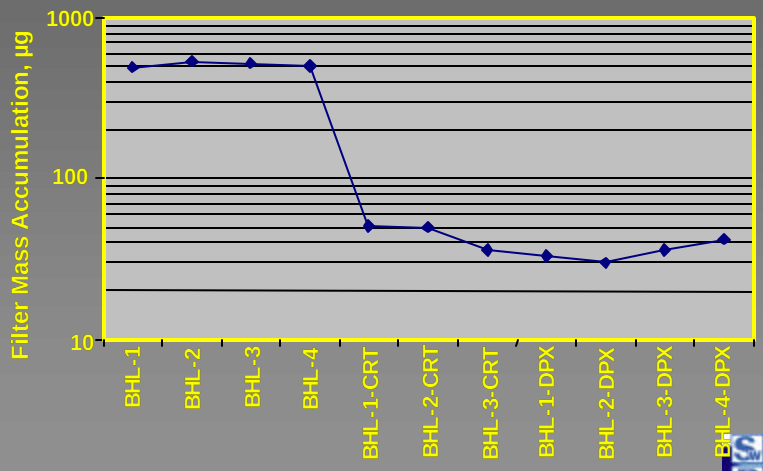
FTP CVS Filter Weight Gain For Without and With Traps- TX-40 Filter Media



BHL PM Emissions For Engine Without and With Traps-TX-40 Filter Media



BHL CVS Filter Weight Gain Without and With Traps-TX-40 Filter Media

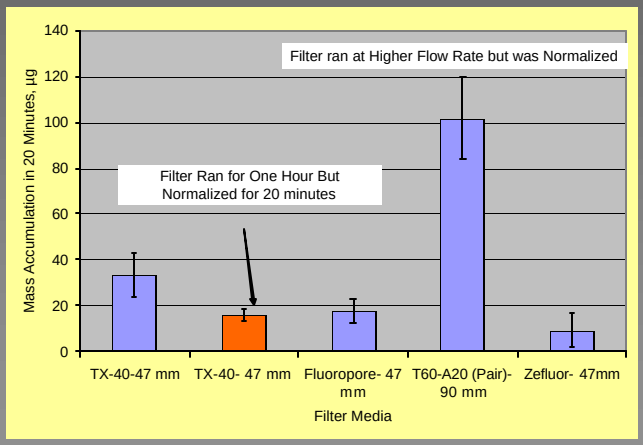


Transient Comparisons Using CVS TX-40 Filters

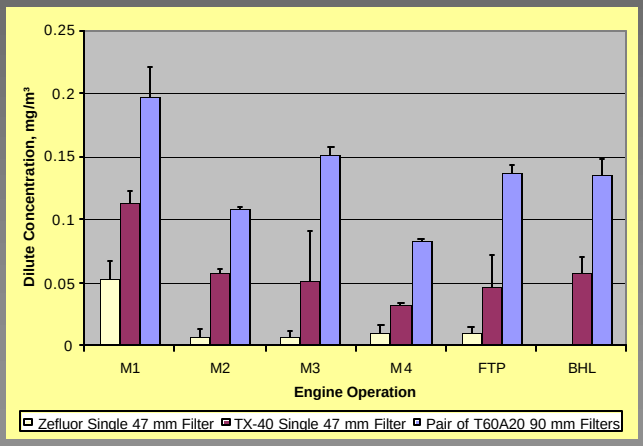
(One TEOM Filter Was Used for All Three Repeats of an FTP)

Transient Cycle	TEOM/CVS	QCM/CVS
Baseline FTP	0.88	1.19
Baseline BHL	0.94	1.22
CRT Trap FTP	0.27	0.44
CRT Trap BHL	0.60	0.24
DPX Trap FTP	0.10	0.51
DPX Trap BHL	0.16	0.37

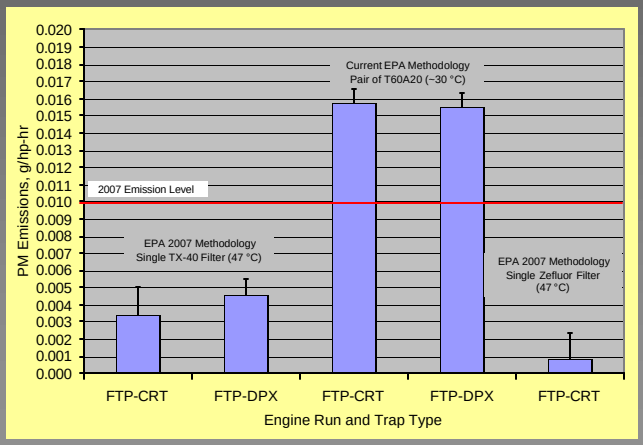
CVS Filter Tunnel Blank Using Different Filter Media



Comparison of PM Emissions Using Different Filter Media



Influence of CVS Filter Media on the FTP Transient Emission Level for an Engine Equipped with Trap



Conclusions

- **This work was exploratory in nature, and more work is needed utilizing the new information learned during this study to make more robust conclusions. The following statements, however, can be made:**
  - Filter Media selected for PM collection seemed to affect the PM emission level significantly. The Zefluor filters, which are Teflon Based, gave the lowest emission level.
  - The data presented were not corrected for Tunnel Blank where filter collection from the CVS was taken without engine running. Tunnel Blank PM mass was very close to the amount of mass collected during testing with a Trap.
  - Significant PM emission variability was observed with Zefluor Filters, possibly due to the very low emission level which was one order of magnitude below the 2007 PM standard
  - The TEOM filter change after every test seemed to increase the emission level reported and improve the correlation with CVS. However, when Zefluor Filters were used the TEOM read negative.
  - The use of Zefluor filters improved the correlation between the QCM and the CVS. The use of such filters that seem to minimize the collection of gas phase material may open up the possibility of finding an alternative method for the filter method.
  - More detail analysis of this work should be made available in future publications