Update on 2007 Diesel Particulate Measurement Research (Project E-66)

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Presented by

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11th DEER Conference, August 21-25, 2005

Acknowledgments

- The E-66 Project is Sponsored by:
  - Coordinating Research Council (CRC)
  - Department of Energy/National Renewable Energy Laboratory (DOE/NREL)
  - Environmental Protection Agency (EPA)
  - Engine Manufacturers Association (EMA)
  - California Air Resources Board (CARB)

Project E-66 Panel Members

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Mr. Brent Bailey, CRC
Dr. Ewa Bardasz, Lubrizol
Dr. Nick Barsic, John Deere
Mr. Mike Bogdanoff, SCAQMD
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Mr. Bill Trestrail, International Truck and Engine Corp.
Mr. Ken Wright, ConocoPhillips, Inc.

Project E-66 Main Objectives

- Phase 1
  - To develop a reference filter method for PM measurement that accounts for or minimizes positive and negative measurement artifact associated with gas phase adsorption or desorption from filter media during PM sampling
  - To evaluate alternative real time PM sampling methods that correlate well with the newly developed filter method. Particle instruments included the SMPS, EEPS, QCM, and DMM-230.
- Phase 2
  - To investigate the influence of dilution conditions on particle mass measurement using the 2007 CVS sampling technique
- Phase 3
  - To correlate PM measured using CVS with PM measured using partial flow sampling systems

Introduction

- Work under Phase 1 of Project E-66 was already completed. The findings were presented at the 2004 DEER Conference, and at the 2005 CRC Workshop. The final report on Phase 1 was submitted to CRC and can be downloaded from CRC Website at: http://www.crcao.com/reports/recentstudies2005/Final%20Report-10415-Project%20E-66-Phase%201--R3.pdf

- This presentation focuses on Phase 2 of Project E-66, including the influence of dilution conditions on particle mass measurement

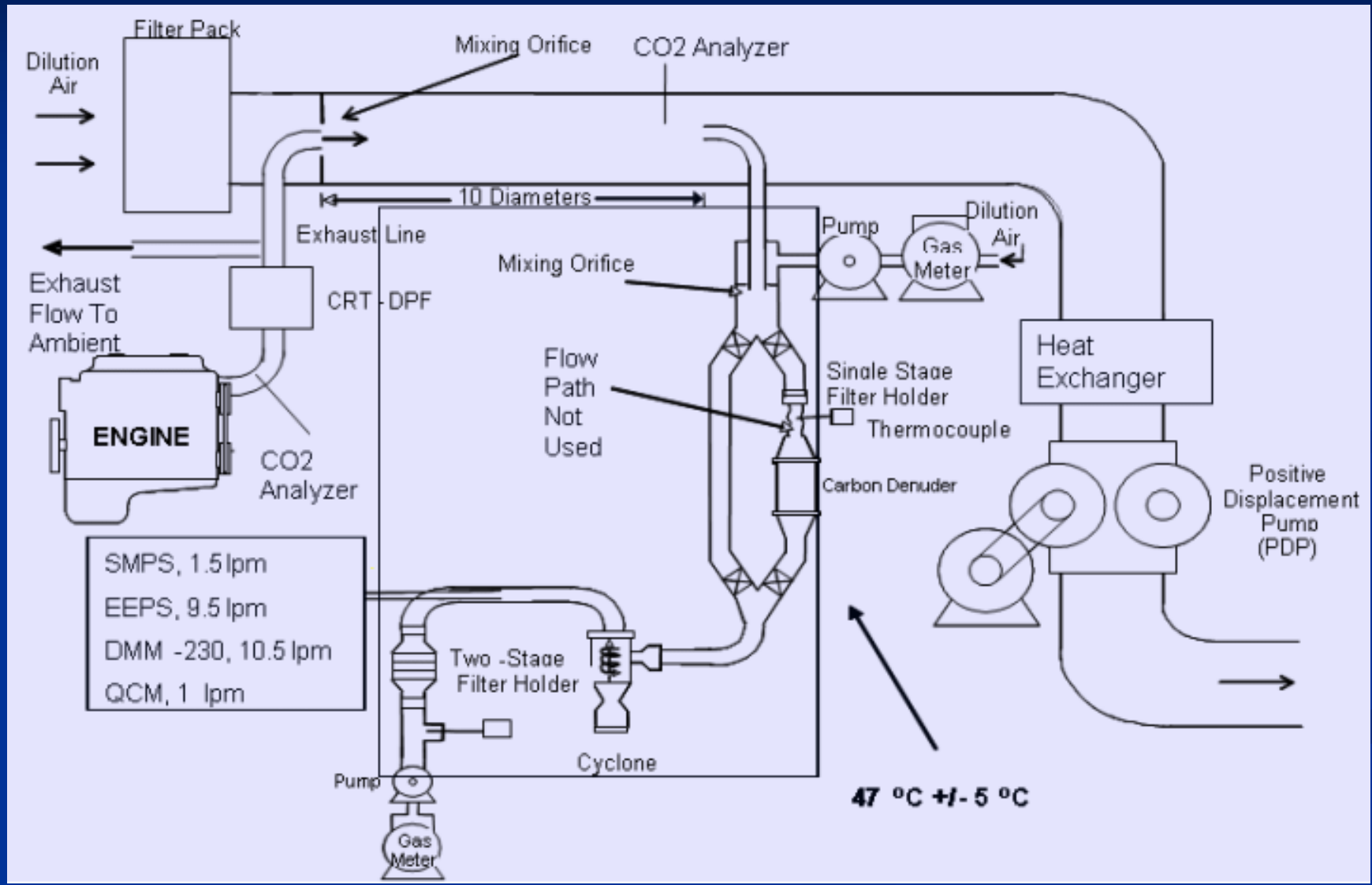
Outline

- Experimental Setup
- Influence of Dilution Parameters on Particle Measurement:
  - CVS Primary Dilution Ratio
  - CVS Primary Dilution Residence Time
  - Secondary Dilution Ratio
  - Secondary Dilution Residence Time
- Conclusions

Diesel Engine, DPF, Oil, and Fuel for E-66

- Engine:
  - 1998 DDC Series 60, 12.7 liter, heavy-duty on-highway diesel engine
- Diesel Particulate Filter (DPF)
  - Johnson Matthey CRT
- Oil
  - Experimental oil- Lubrizol 2007 projected specification
- Fuel
  - Ultra low sulfur diesel (ULSD) fuel, 7ppm sulfur content- Sinclair 2007 projected specification

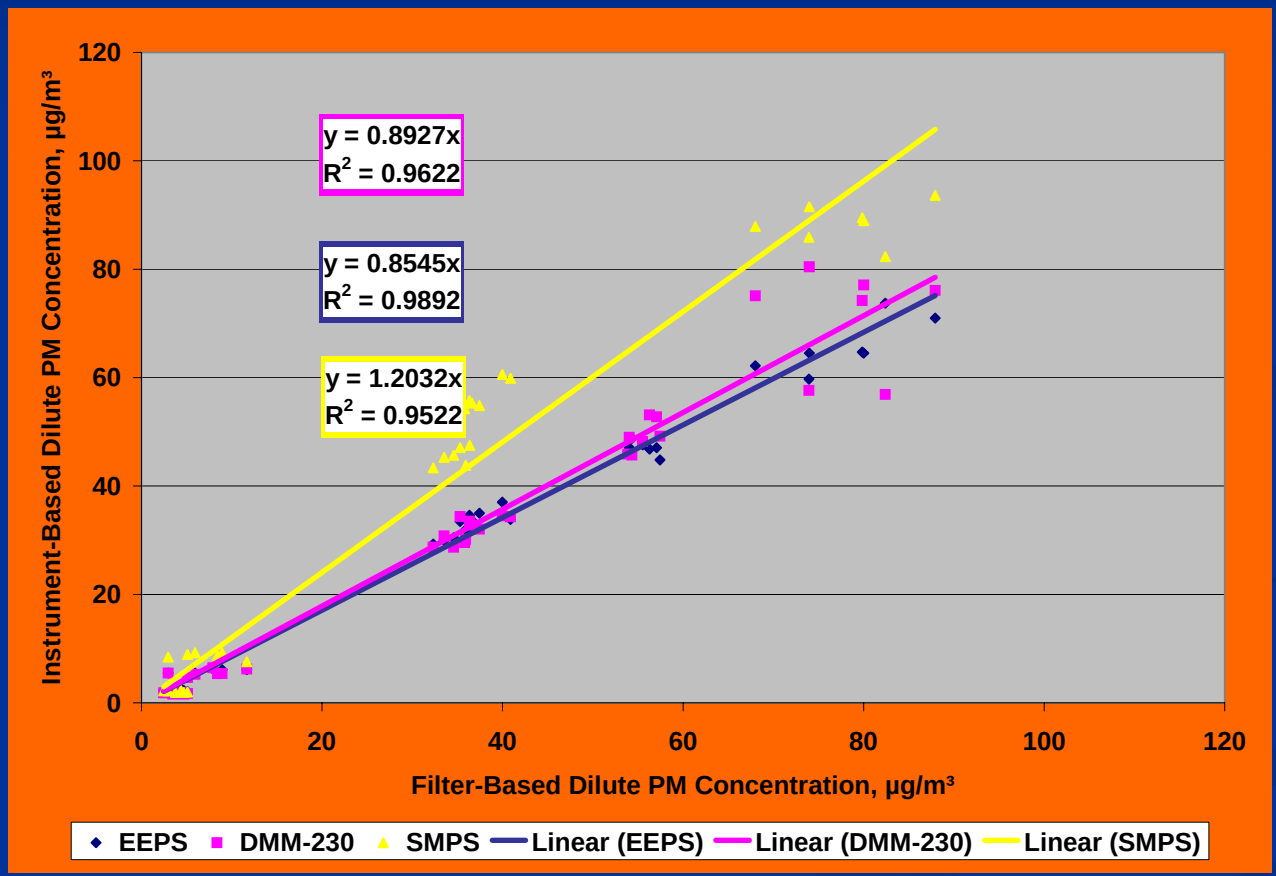
Experimental Setup



Real Time Particle Instruments

- Scanning Mobility Particle Sizer (SMPS, TSI)
- Engine Exhaust Particle Sizer (EEPS, TSI)
- Quartz Crystal Micro Balance (QCM, Sensors)
- Dekati Mass Monitor (DMM-230, Dekati)

Improved Correlation Between Filter-Based and Instrument-Based PM (CRT-DPF with Bypass)



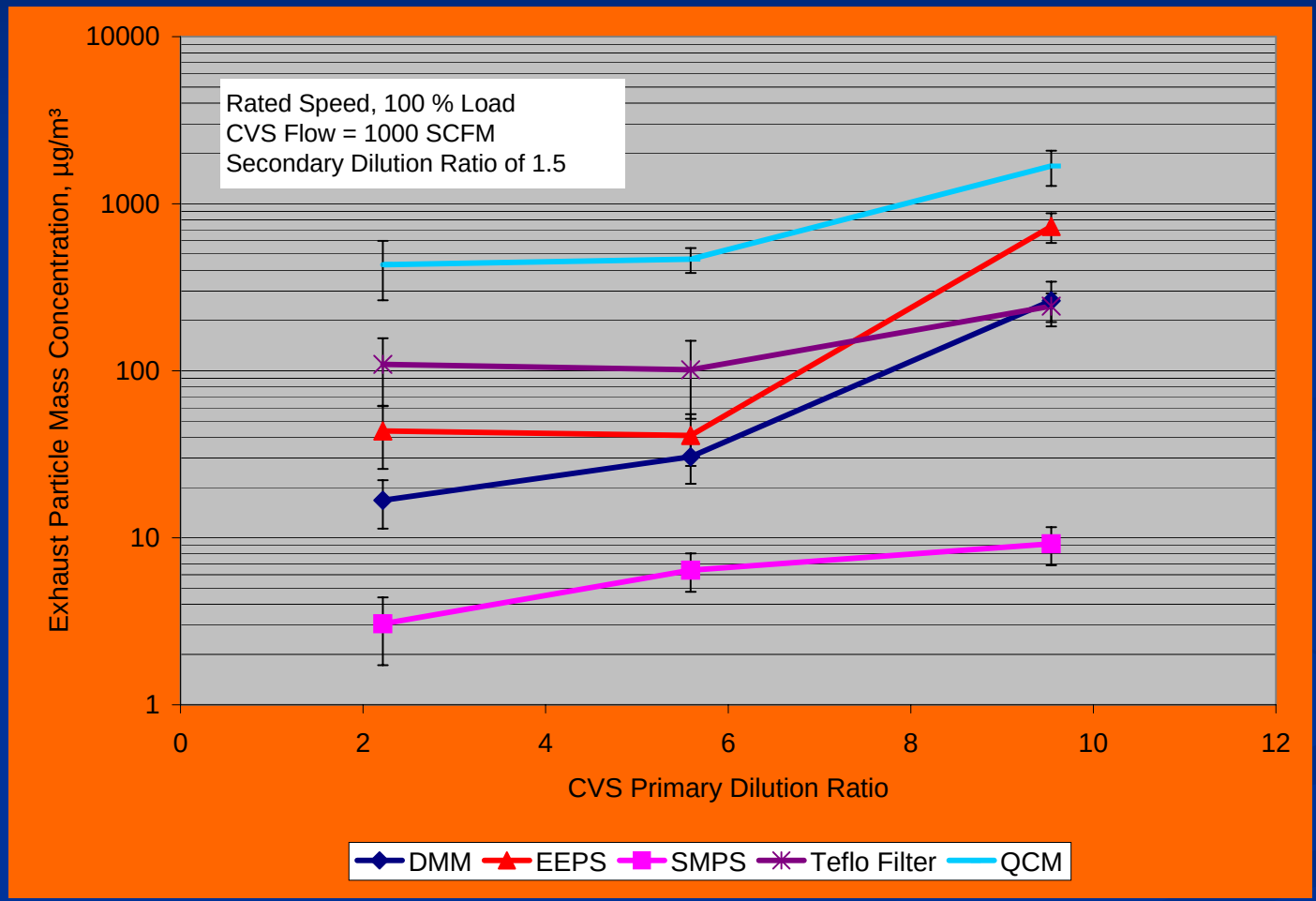
It is important to note that this correlation *does not apply* to measurement downstream of *CRT-DPF without bypass, where the dilute PM concentration is very low and dominated by volatile material*

Basis for Using Real Time Instruments

- Real time instruments for dilute exhaust particle measurement were used for this study because they demonstrated a good correlation with the filter based-method, during Phase 1 of Project E-66, using DPF with bypass
- For this work, real time instruments were used instead of filters to:
  - Investigate a wide variety of dilution conditions in a short period of time because filters require long sampling time for adequate loading
  - To allow, in a follow-up work, selected verification of the results using filters instead of real time instruments

Higher CVS Primary Dilution Ratio Leads to a Higher PM Emission (Rated Power)

(100 μg/m3 is equivalent to 0.0005 g/hp-hr, 5 % of the 2007 PM Standard)



Note that the concentration is reported after being multiplied by the total dilution ratio. The measured dilute concentration was very low for reliable particle mass measurement by EEPS, SMPS, and DMM-230

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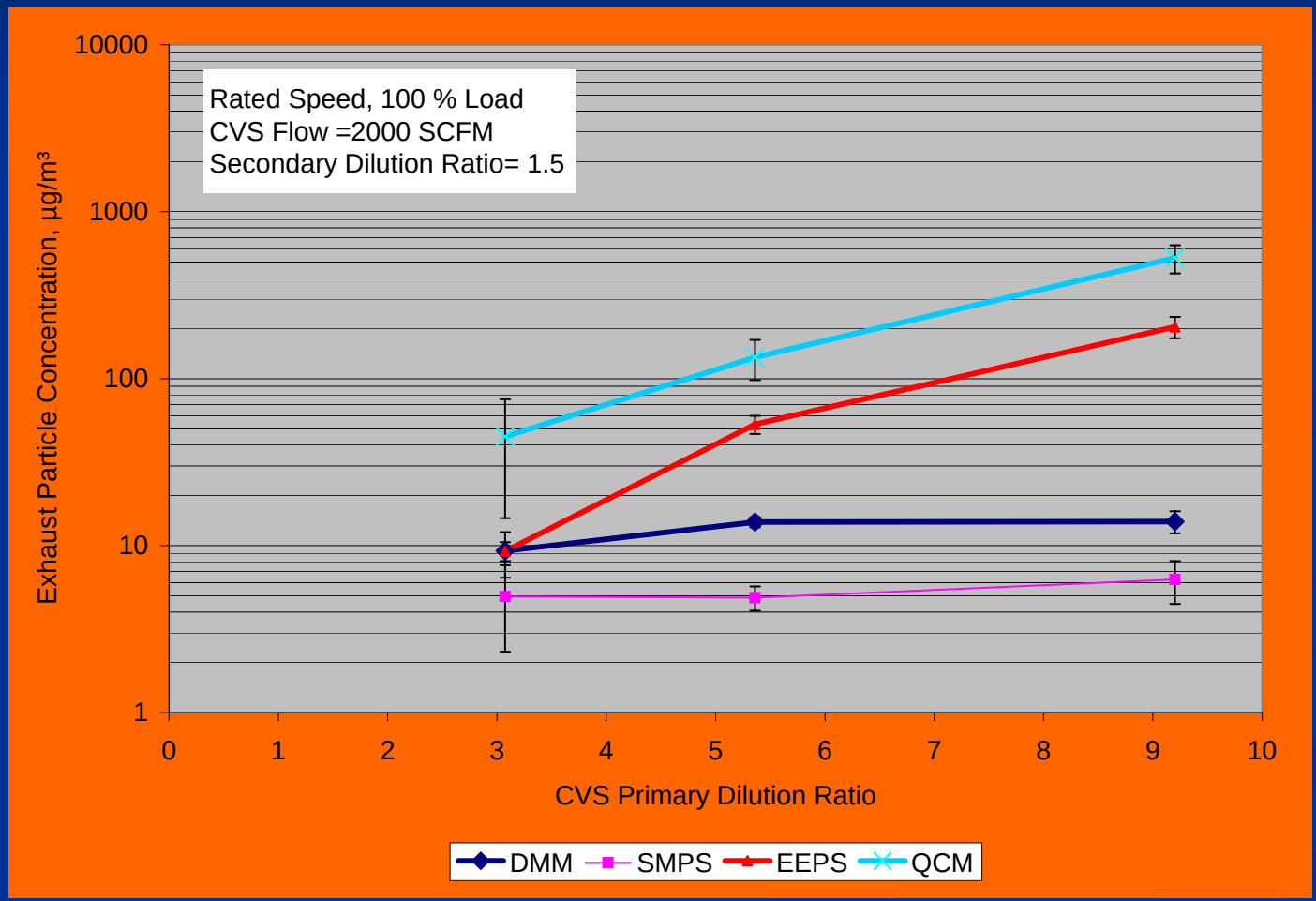
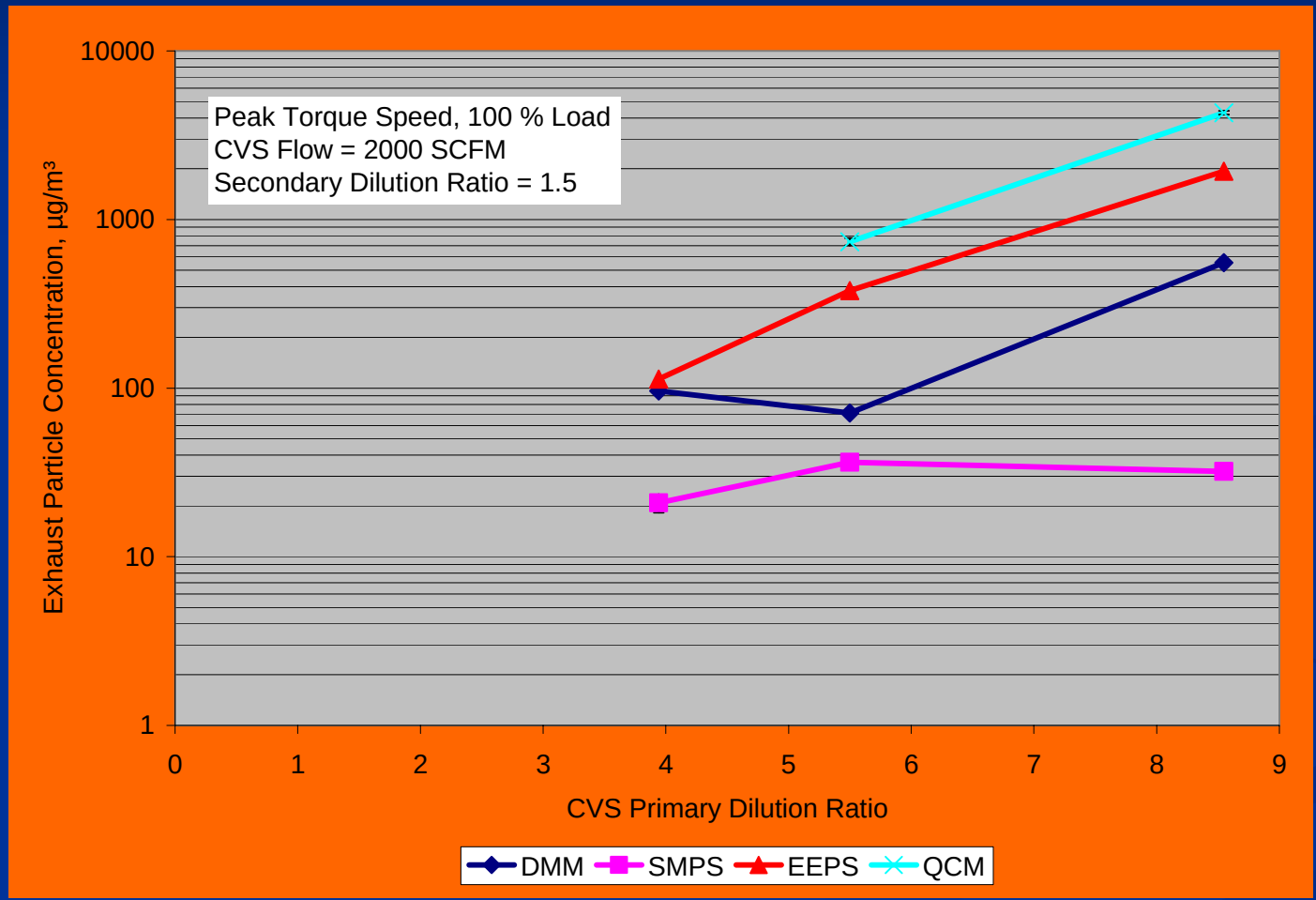


Note that the concentration is reported after being multiplied by the total dilution ratio. The measured dilute concentration was very low for reliable particle mass measurement by EEPS, SMPS, and DMM-230

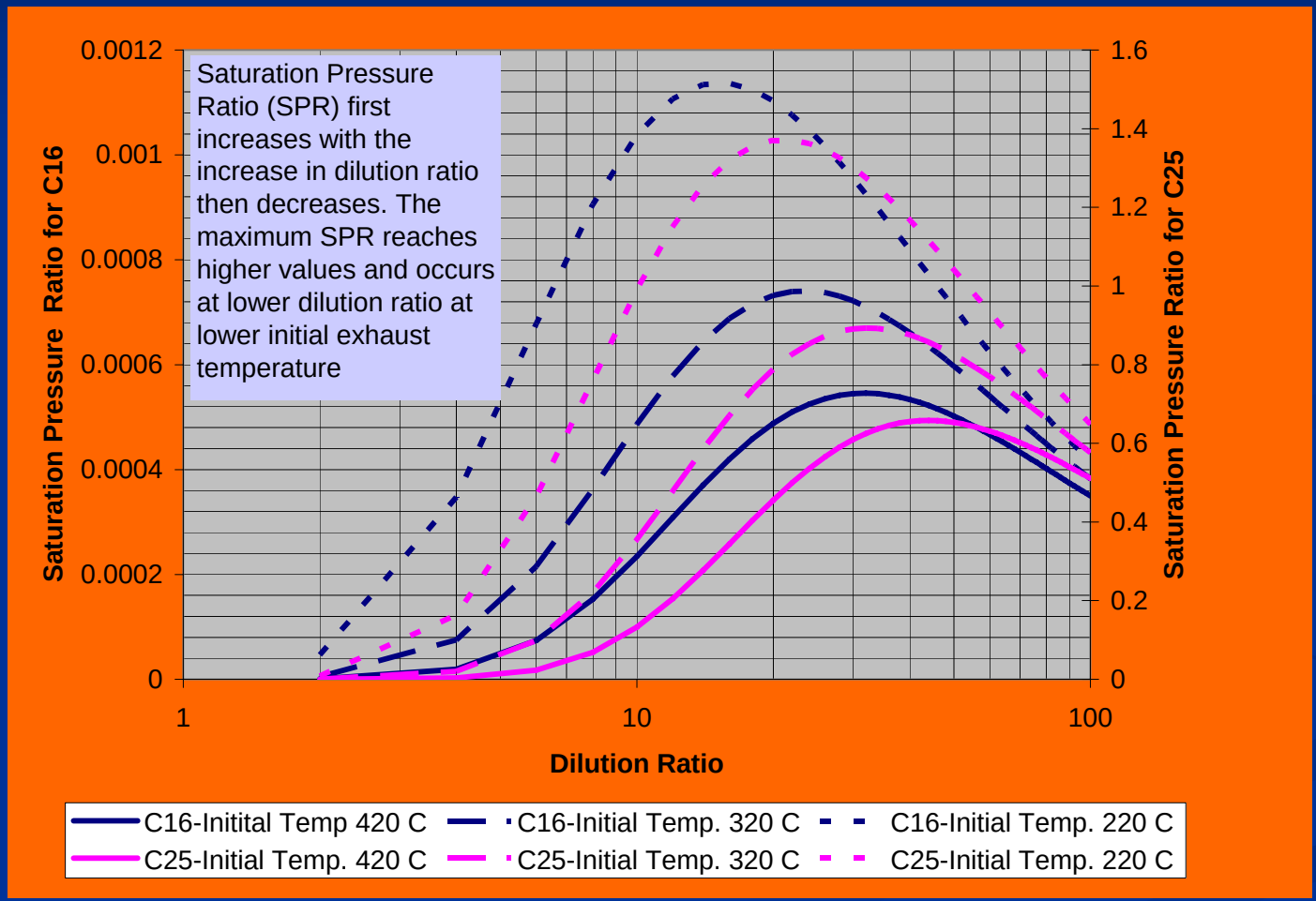
Higher CVS Primary Dilution Ratio Leads to a Higher PM Emission (Peak Torque)

(100 μg/m3 is equivalent to 0.0003 g/hp-hr, 3 % of the 2007 PM Standard)



Note that the concentration is reported after being multiplied by the total dilution ratio. The measured dilute concentration was very low for reliable particle mass measurement by EEPS, SMPS, and DMM-230

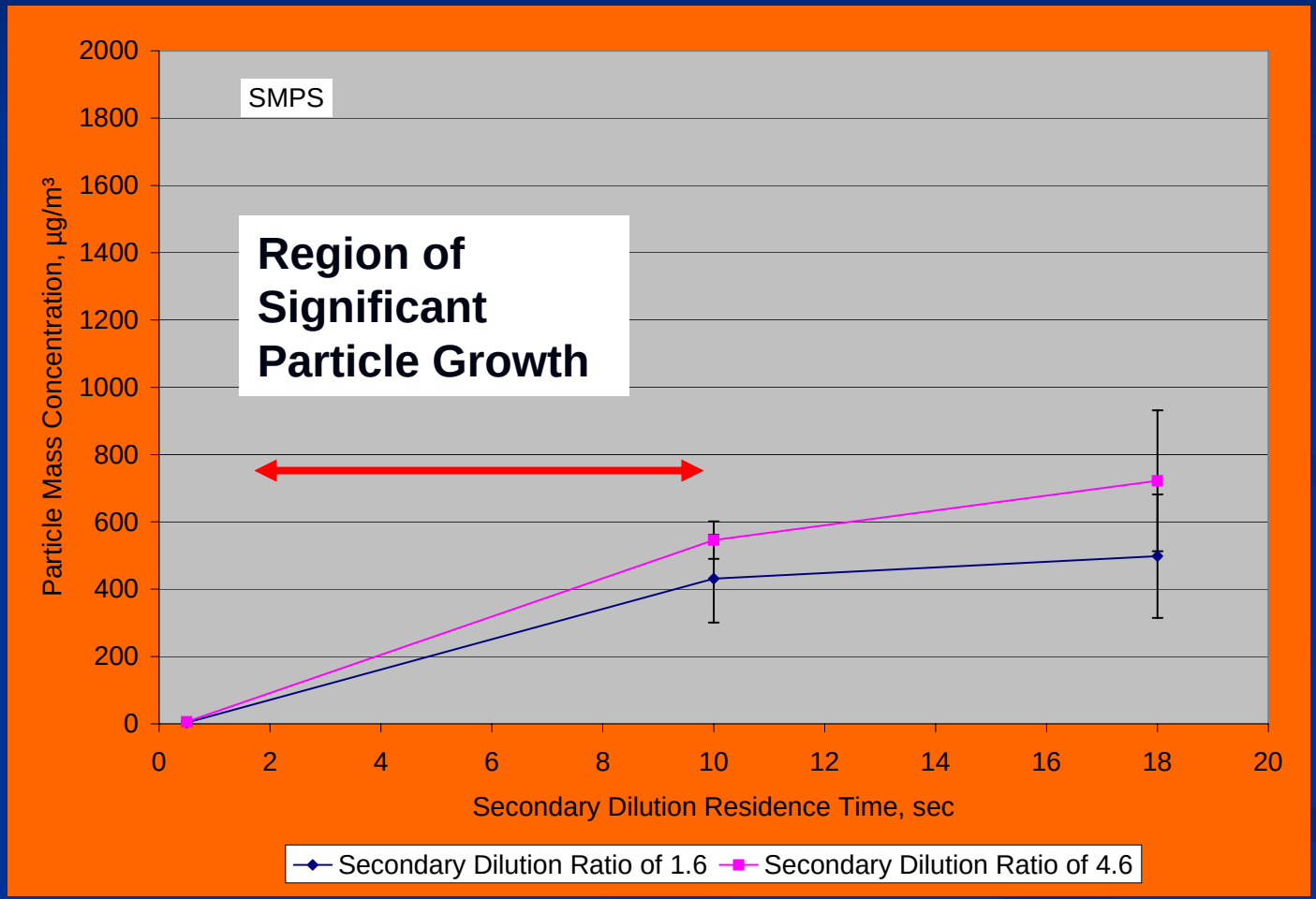
Calculation Revealed that Higher CVS Primary Dilution Ratio Leads to a Higher Saturation Pressure Ratio in the Dilution Ratio Range Below 40, Depending on Initial Exhaust Temperature



Saturation pressure ratio is the ratio of partial pressure over vapor pressure, where higher ratios favor particle nucleation and growth.

Longer Residence Time Leads to an Increase in Particle Mass Emission (Rated Speed, 100 % Load)

(100 μg/m3 is equivalent to 0.0005 g/hp-hr, 5 % of the 2007 PM Standard)



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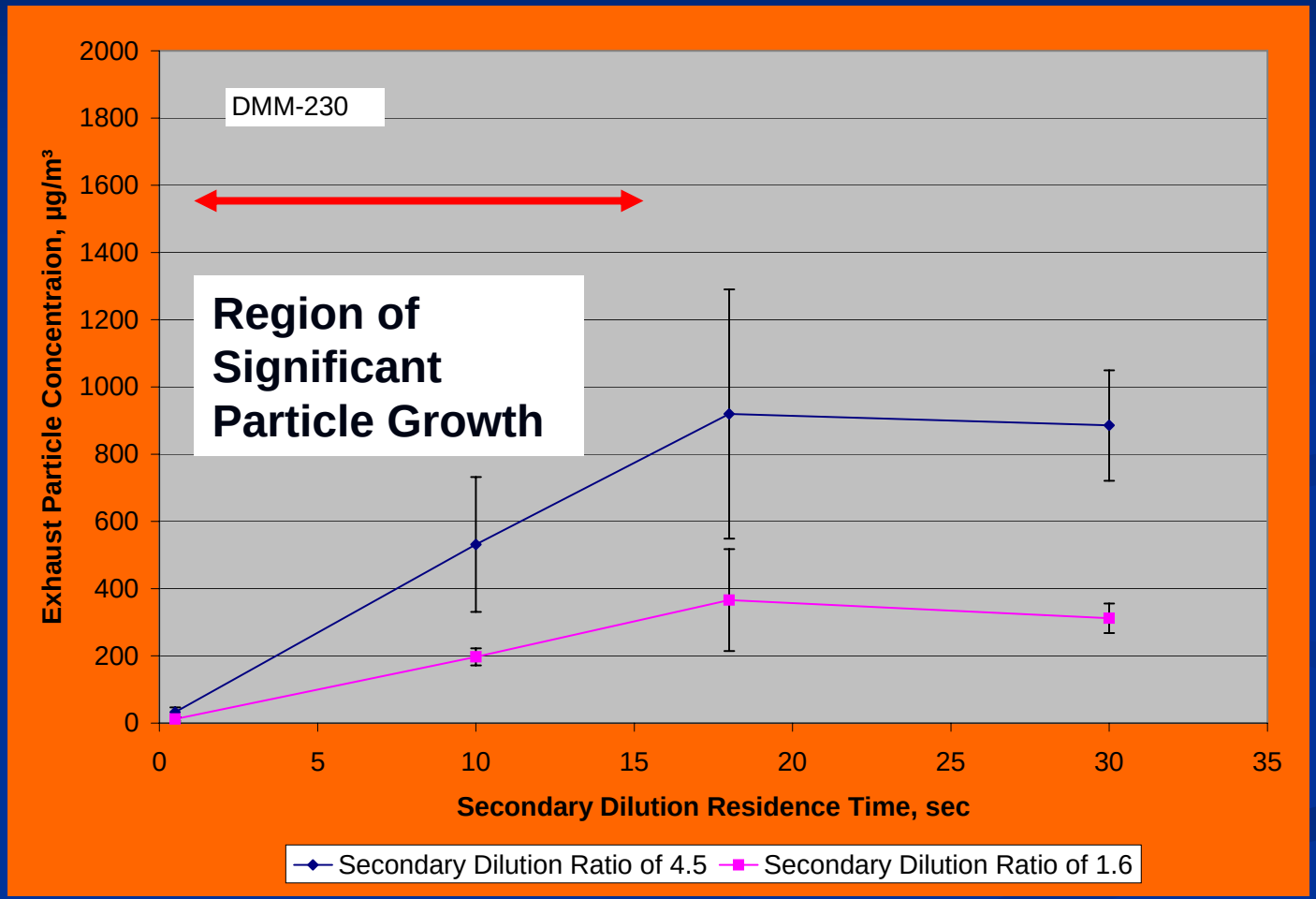

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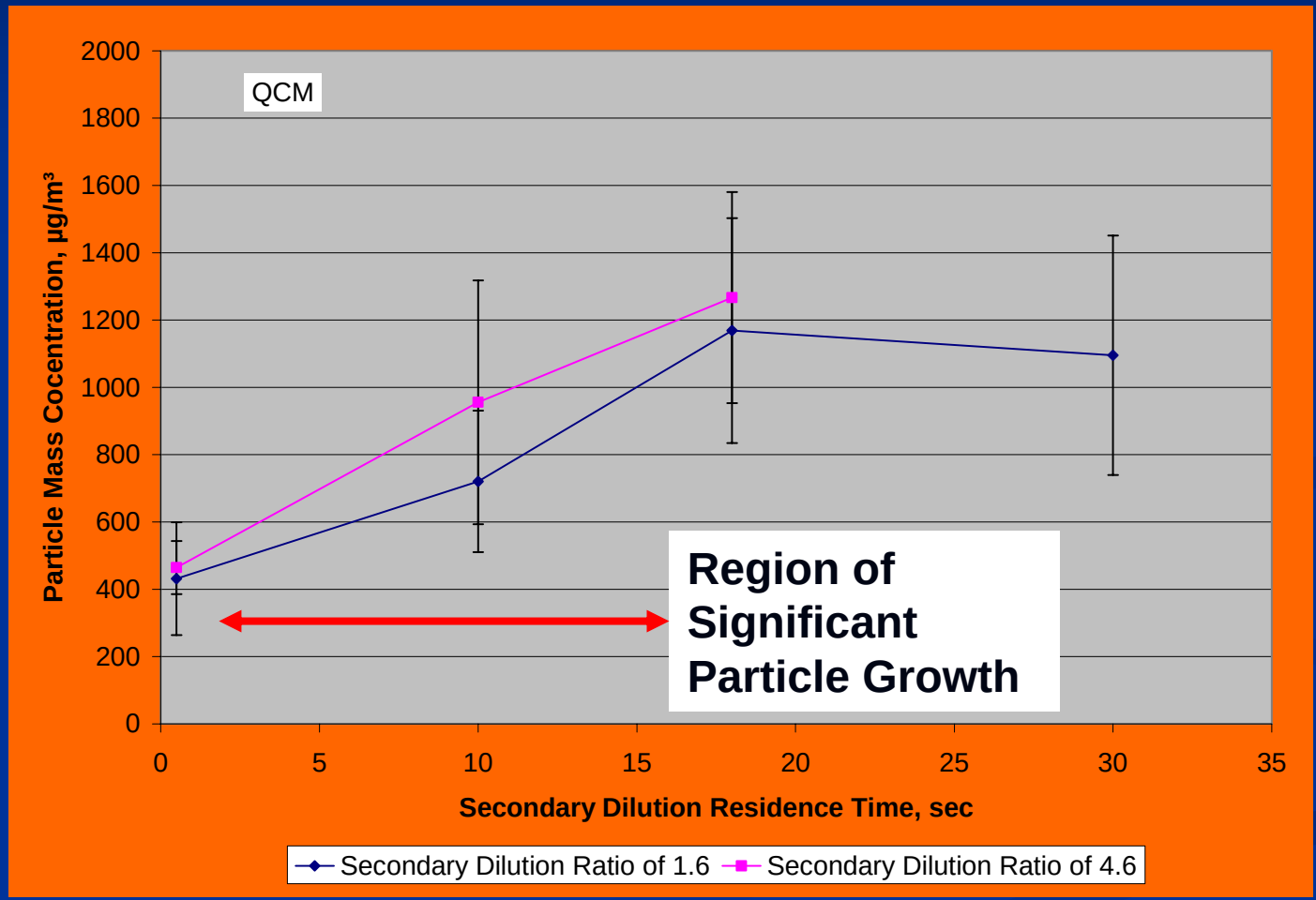
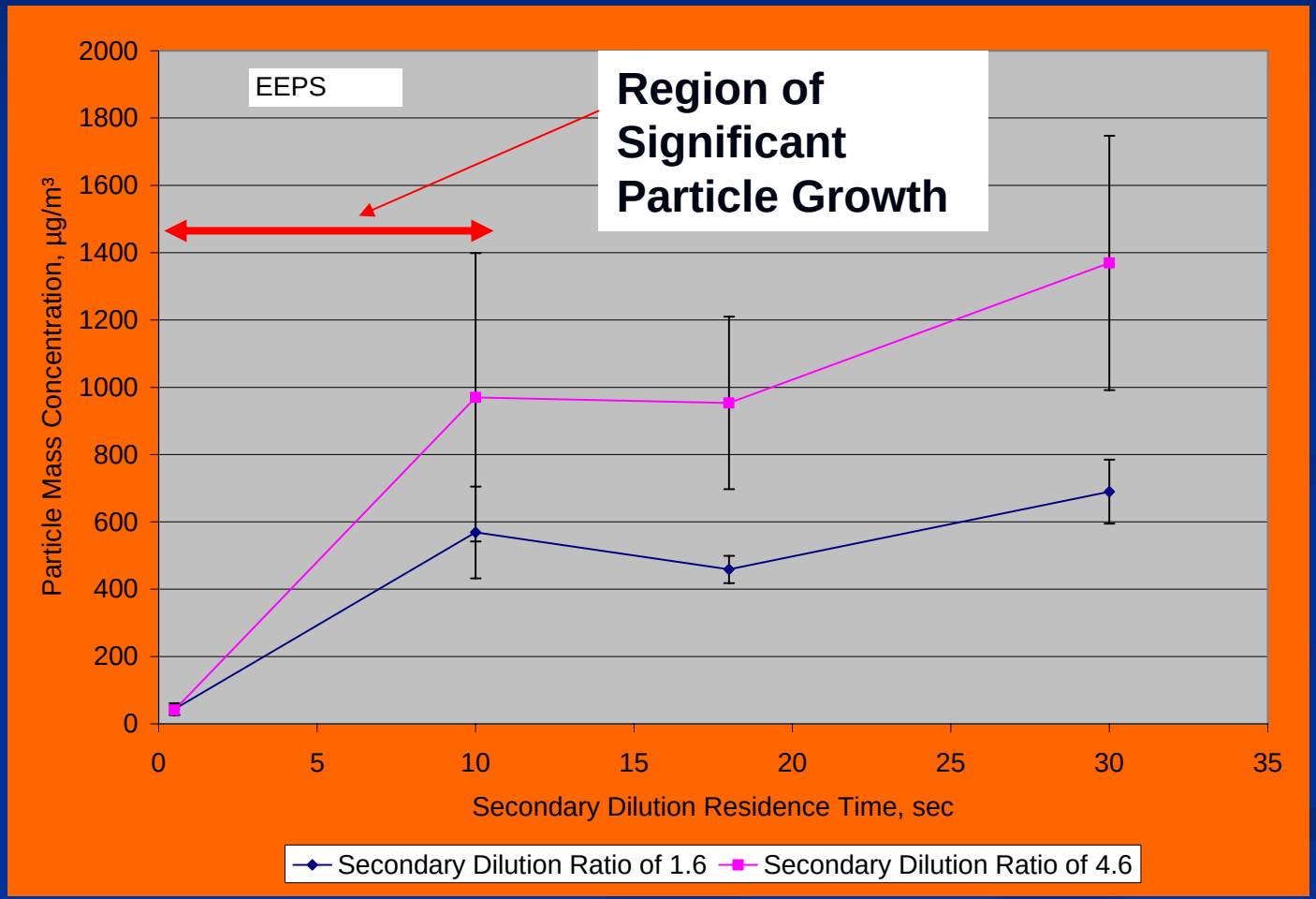
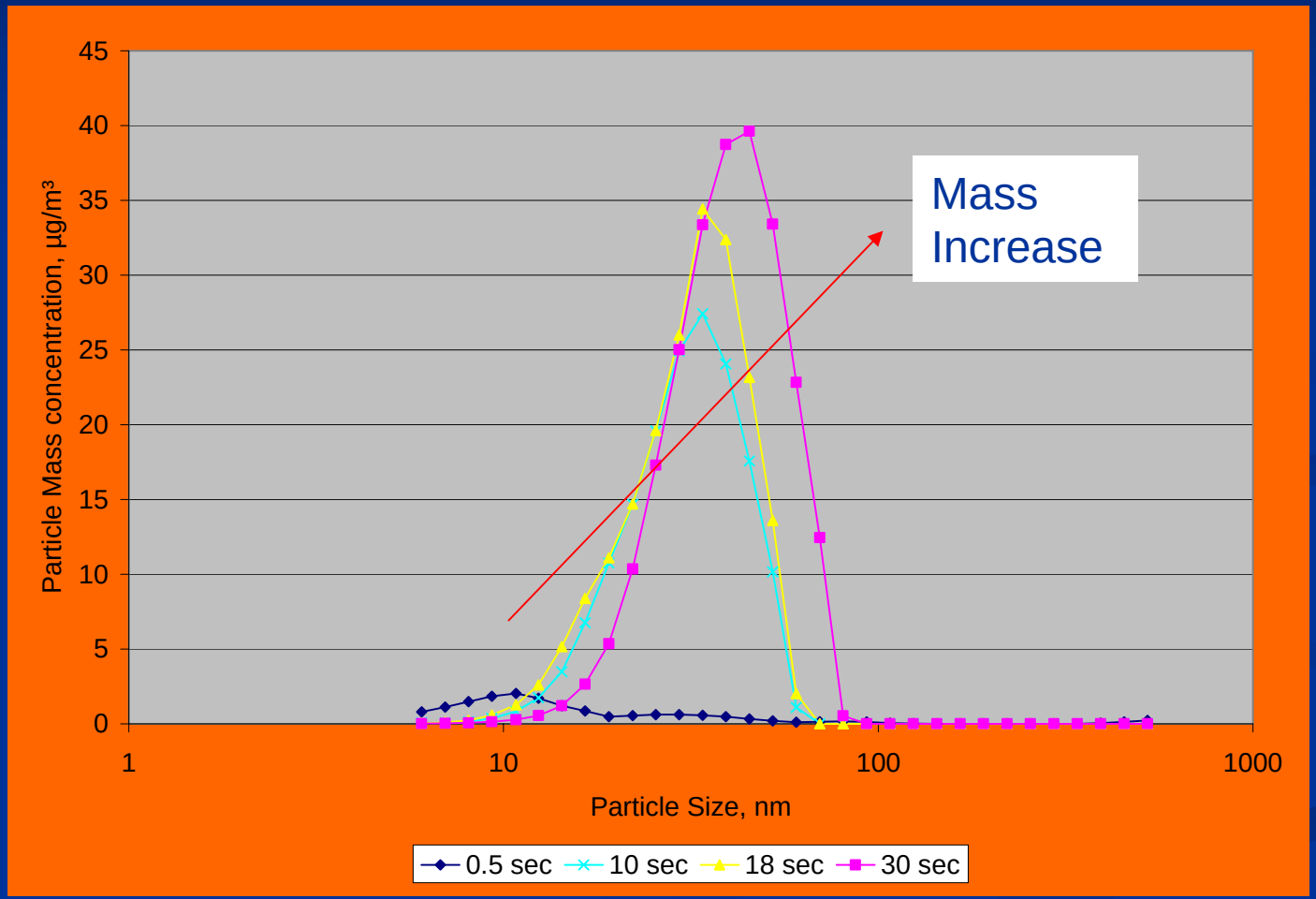


Longer Residence Time Lead to a Significant Increase in Particle Mass Emission (Rated Speed, 100 % Load)

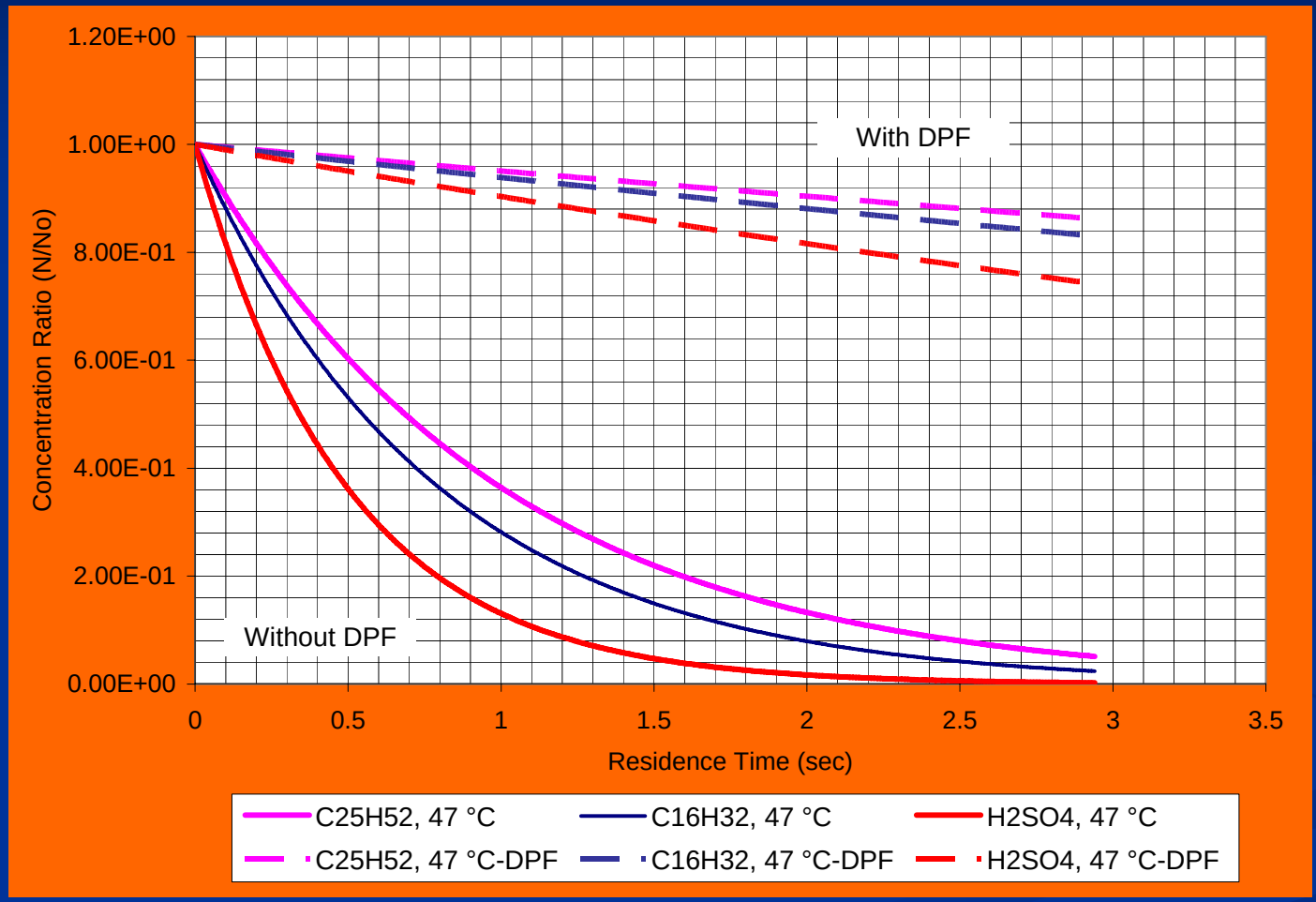
(100 μg/m3 is equivalent to 0.0005 g/hp-hr, 5 % of the 2007 PM Standard)



Mass-Weighted Size Distribution at Different Secondary Dilution Residence Times Using EEPS



Based on Theoretical Derivation, Residence Time Plays More Important Role for Engine With a DPF Compared to That Without a DPF



When the soot is captured by the DPF, it takes longer for the gas phase material to be depleted due to the lack of adsorption sites normally provided by soot particles for engines without a DPF.

Conclusions

- Longer residence time and higher primary dilution ratio lead to an increase in particle mass emissions as indicated by the real time particle instruments. It is important to verify this phenomenon with the use of Teflon membrane filter media.

- Residence time seems to play a very important role in affecting particle mass measurement downstream of a DPF, using real time particle instruments. This is due to the lack of soot that typically serves as an adsorption site, which contributes to rapid depletion of volatile and semi-volatile material during exhaust dilution and cooling.

- Even with the longest residence time used in this work, particle mass emissions remained below the EPA 2007 PM standard. It typically ranged from 3 to 5 percent of the standard at a residence time of 0.5 second, and it increased to about 50 to 75 percent of the 2007 standard at a residence time of 10 to 15 seconds.

- With the lack of a reference PM standard method for PM instrument characterization and calibration, real time particle instruments, relying on assumptions to derive particle mass, may not give accurate PM emission results, but good qualitative results, particularly when the measured mass concentration is below 10 to 20 μg/m3, and the aerosol is mainly volatile and semi-volatile in nature.

Conclusions (Continued)

- This work was crucial in pointing out deficiencies in the 2007 PM sampling protocol relative to the flexibility in allowing different dilution ratios and residence times because they lead to different PM mass emissions. This was mainly demonstrated by the use of real time particle instruments. It will be important to verify that these results also apply when using Teflon membrane filter media, the EPA acceptable method in measuring PM mass.

- This work was also important in pointing out deficiencies in the use of real time particle instruments as mass measuring devices for laboratory or onboard testing. This is due to the lack of a standard method that verifies the instruments accuracy in measuring PM mass at different particle composition and concentration, and the lack of a well defined dilution system ahead of the real time instruments to perform the onboard measurement.

- This work suggests that more research efforts are needed to understand the effect of dilution parameters on particle mass emissions using Teflon membrane filter media, the current legal method in measuring PM mass. This work also suggests that more research efforts are needed in the area of developing a reference PM standard protocol for real time particle instruments characterization and calibration.