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# Real time particle number weighted size distribution using parallel flow diffusion battery

# Parallel Flow Diffusion Battery for Steady-State and Transient Nanoparticle Measurements

By

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## SUMMARY

A parallel flow diffusion battery (PFDB) was developed to measure particle number weighted size distribution in the nanoparticle size range (particle diameter ranging from 3 nm to 56 nm), in real time, particularly under transient engine operation. The PFDB measures the diffusion diameter of particles that can be considered the most important size characteristic in the nanoparticle size range. Particle diffusion is the main mechanism that leads to particle deposition on surfaces in human lung.

The PFDB compared well with the SMPS. It also showed along with the SMPS that ultra low sulfur diesel fuel, sulfur level of about 1 ppm, reduced nanoparticle emissions by at least a factor of five during both steady-state and transient engine operation. This work also showed that different dilution systems give different nanoparticle emission level, depending on the dilution process and how the sampling was done. This mostly affected volatile particle emissions and not the solid fraction of particulate matter. For example, the CVS full flow dilution tunnel resulted in higher nanoparticle number emissions than the micro-dilution tunnel. A unified measurement approach is needed to have consistency in volatile particle emissions.

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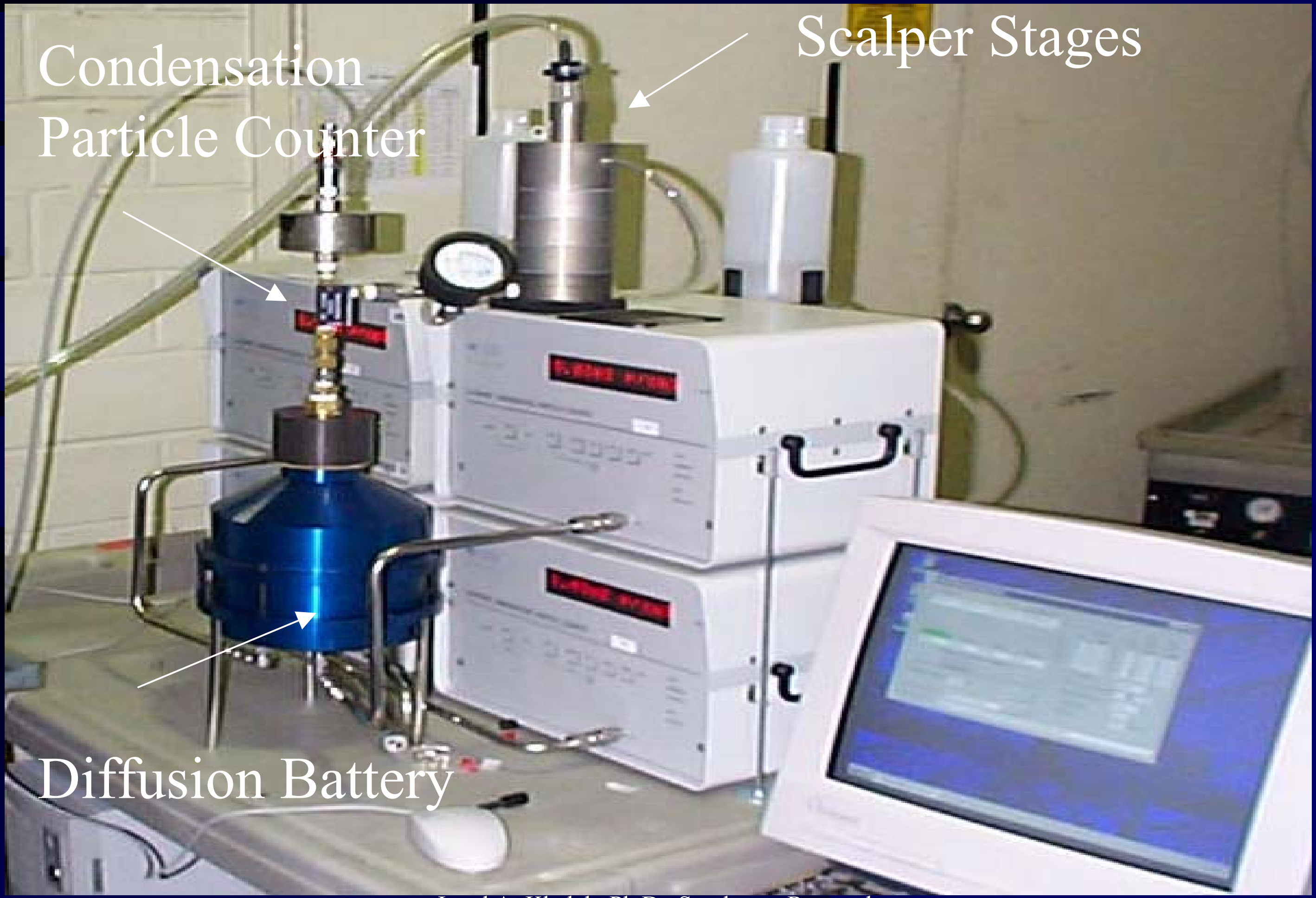
# Background

- Need for Nanoparticle Size Measurements in Real Time. e.g. Transient Engine Operations
- Need for a Representative Size Characteristics in the Nanoparticle Size Range (Dp < 50 nm), e.g. Diffusion Diameter Using a Diffusion Battery

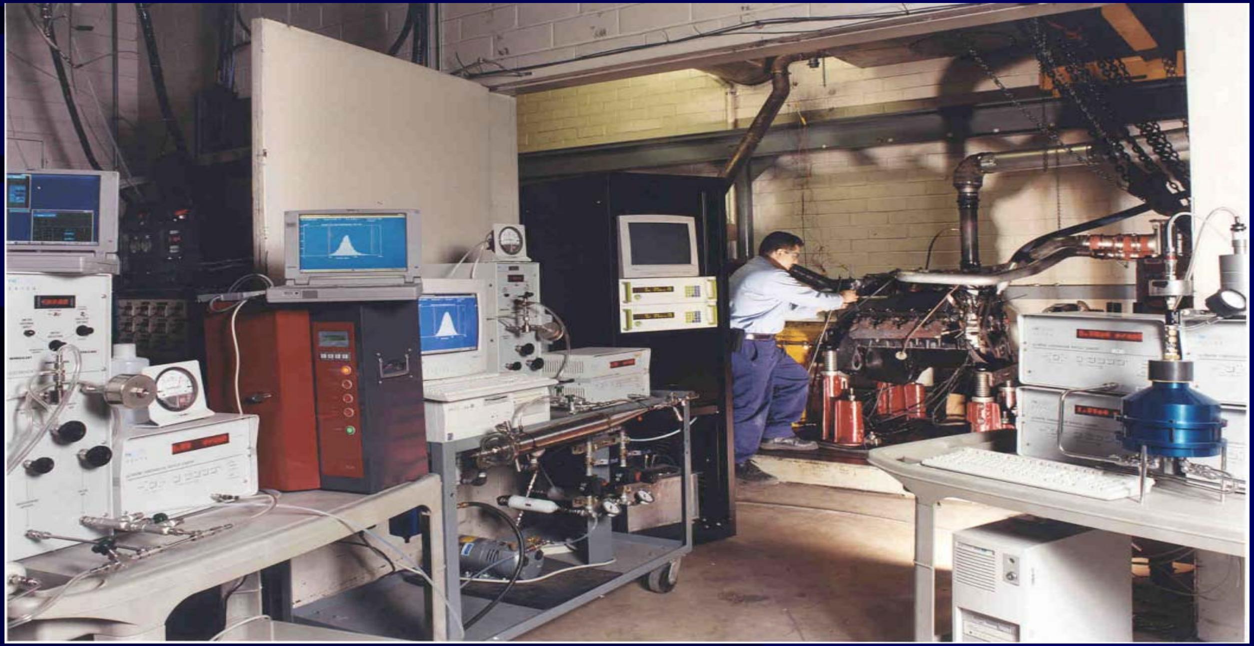
# Parallel Flow Diffusion Battery General Characteristics

- Size Range  Below 56 nm in Aerodynamic Diameter
- Four Diffusion Diameter Size Ranges: 56 nm to 32 nm, 32 nm to 18 nm, 18 nm to 10 nm, and 10 nm to 3 nm
- Real Time Reading Via Four Condensation Particle Counters

# Parallel Flow Diffusion Battery



# Experimental Setup with a Micro-dilution System



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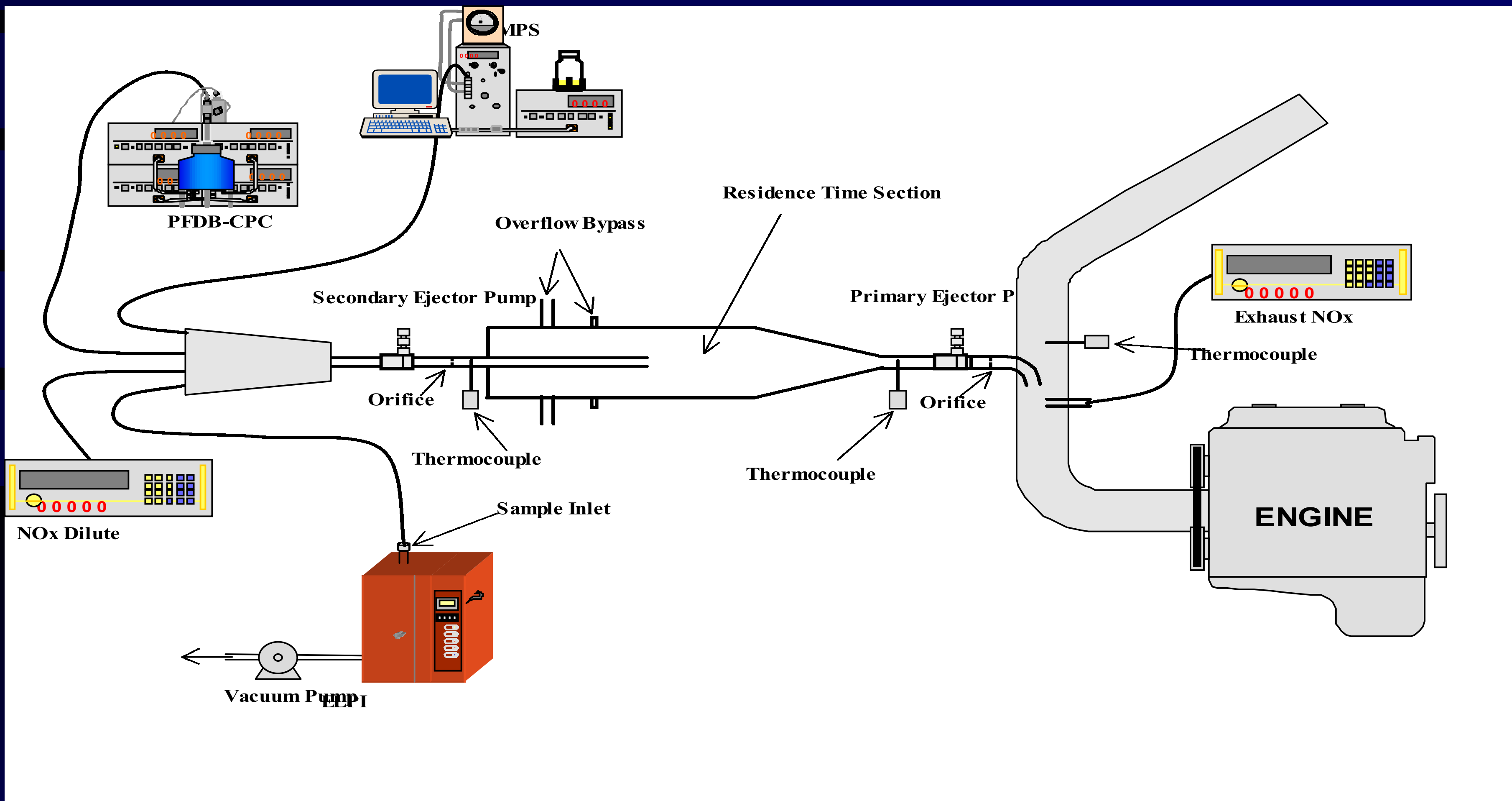
# Experimental Setup



# Legends and Labels

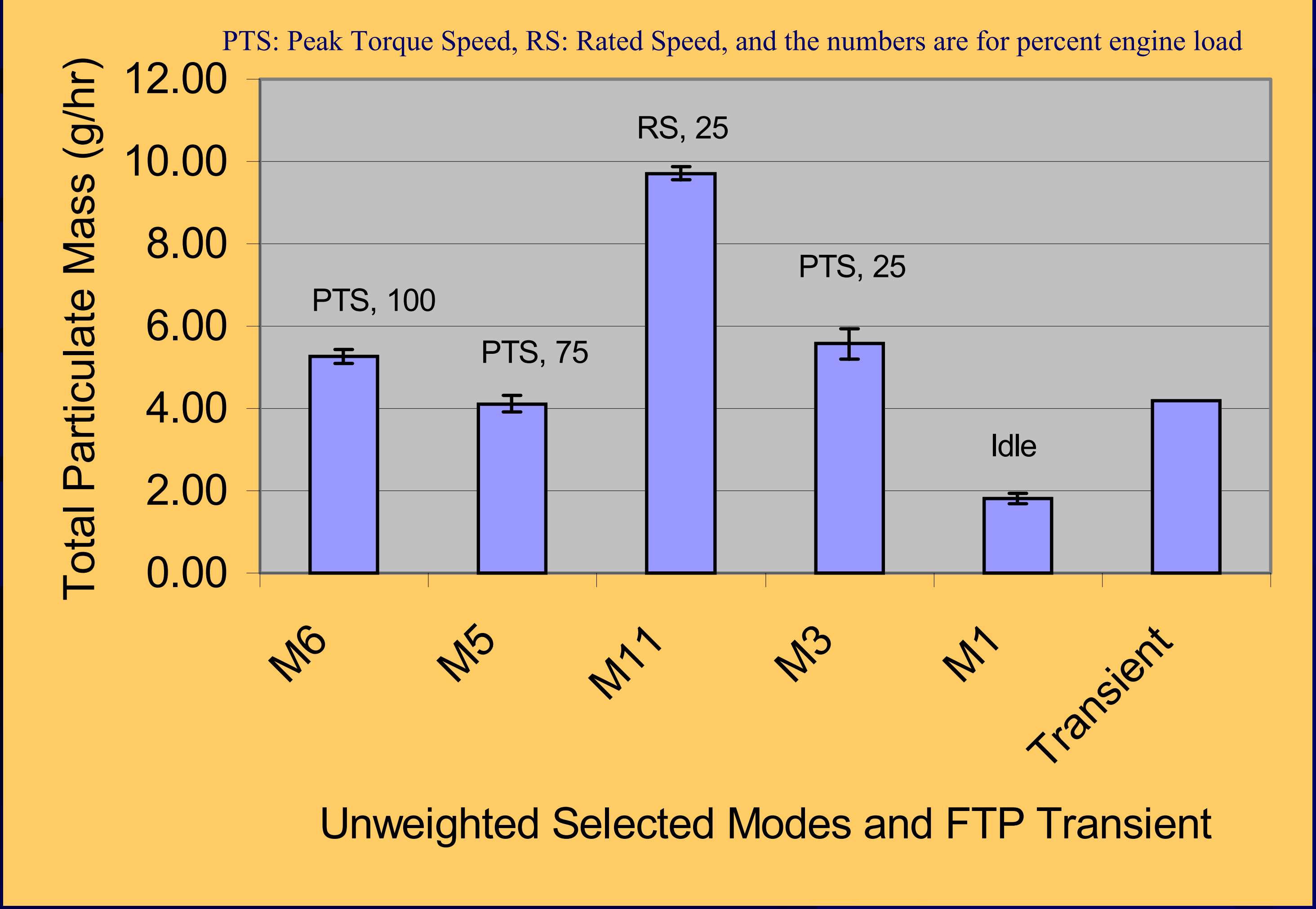
- Fuels:
  - 2D: US On-highway Diesel Fuel, 385 ppm Sulfur
  - LS: 2D Fuel but with Sulfur Fuel Level of 1 ppm

- Steady State Modes
  - M1: Low Idle Speed
  - M3: Peak Torque Speed, 25 Percent Load
  - M5: Peak Torque Speed, 75 Percent Load
  - M6: Peak Torque Speed, 100 Percent Load
  - M11: Rated Power Speed, 25 Percent Load

- Instruments
  - SMPS: Scanning Mobility Particle Sizer
  - PFDB: Parallel Flow Diffusion Battery

- Dilution Systems:
  - MD: Micro-Dilution Tunnel using two-stage ejector pumps. The system is coupled to exhaust pipe 1 ft downstream of engine turbocharger.
  - CVS: Full flow tunnel. A Micro-Tunnel using one stage ejector pump was coupled to sample zone of the full flow CVS to achieve a second stage of dilution.
  - The primary difference between the two tunnel is in the primary dilution stage. The primary dilution ratio with the MD was about 10. The primary dilution ratio in CVS ranged from 4 to 20, depending on engine condition. High dilution at idle, low dilution at Peak torque speed or rated speed.

# Total PM Mass Emissions (385 ppm Sulfur, Steady-State Engine Operation)

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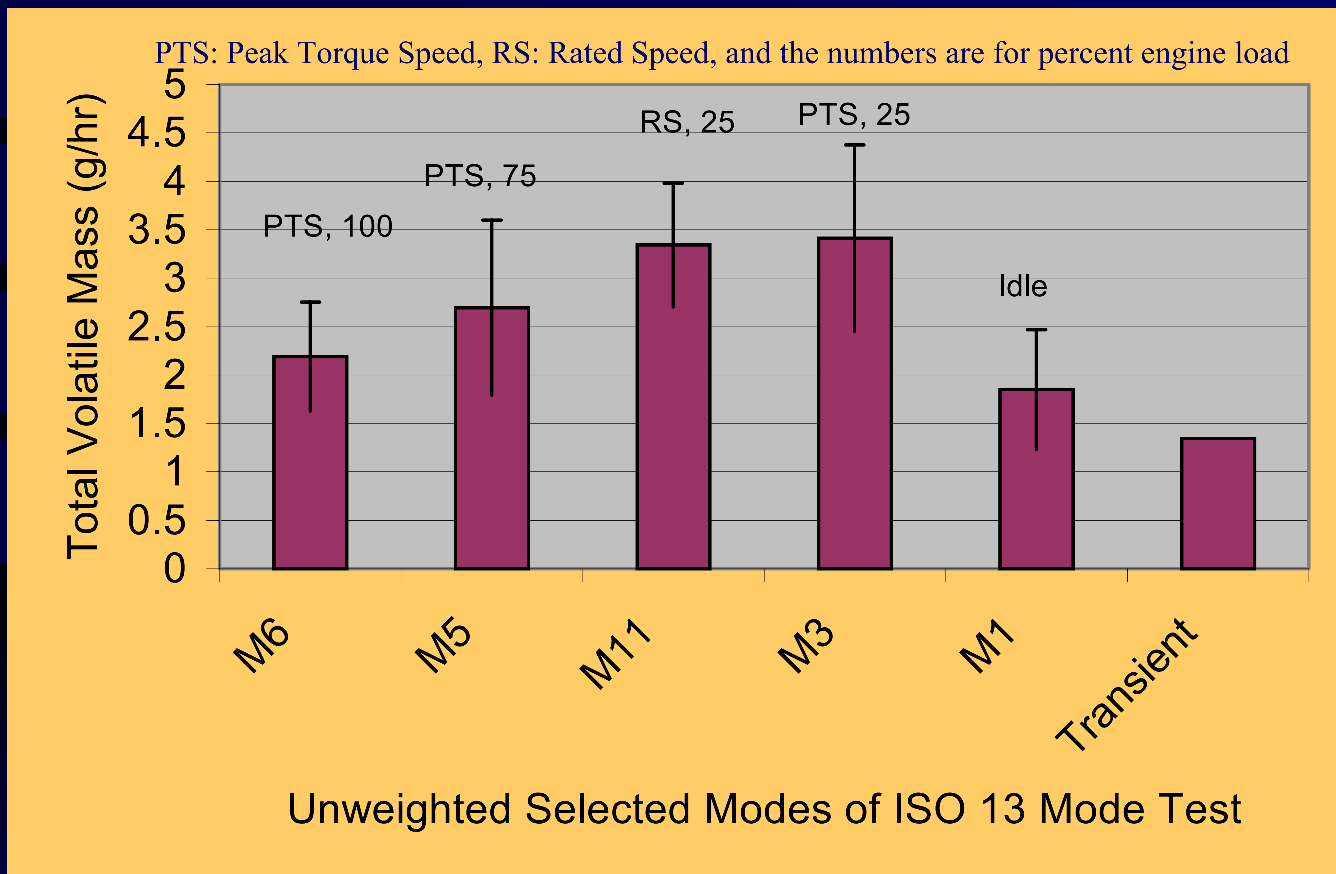
# Total Volatile PM Mass (385 PPM Sulfur, Steady State Engine Operation)

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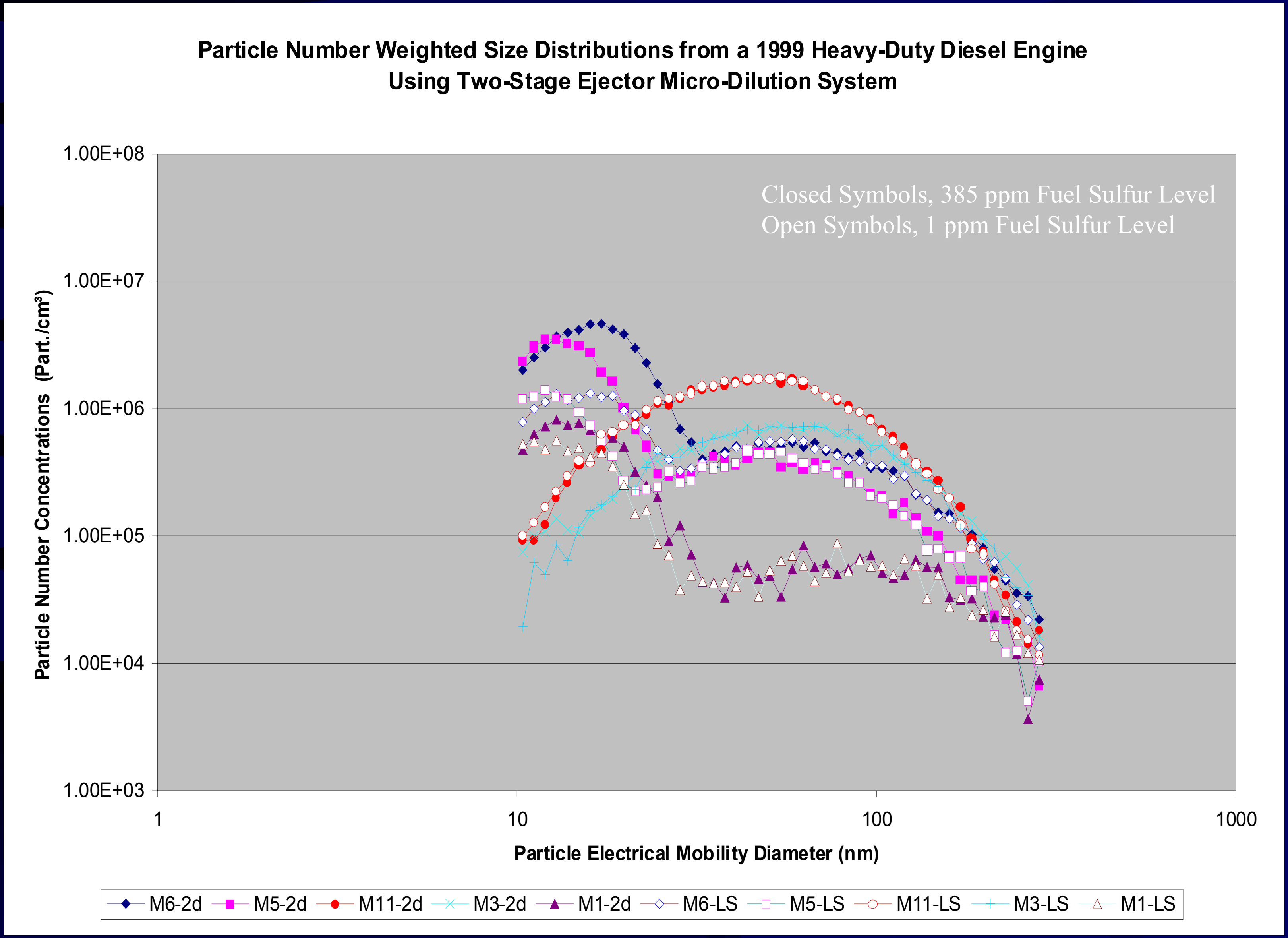


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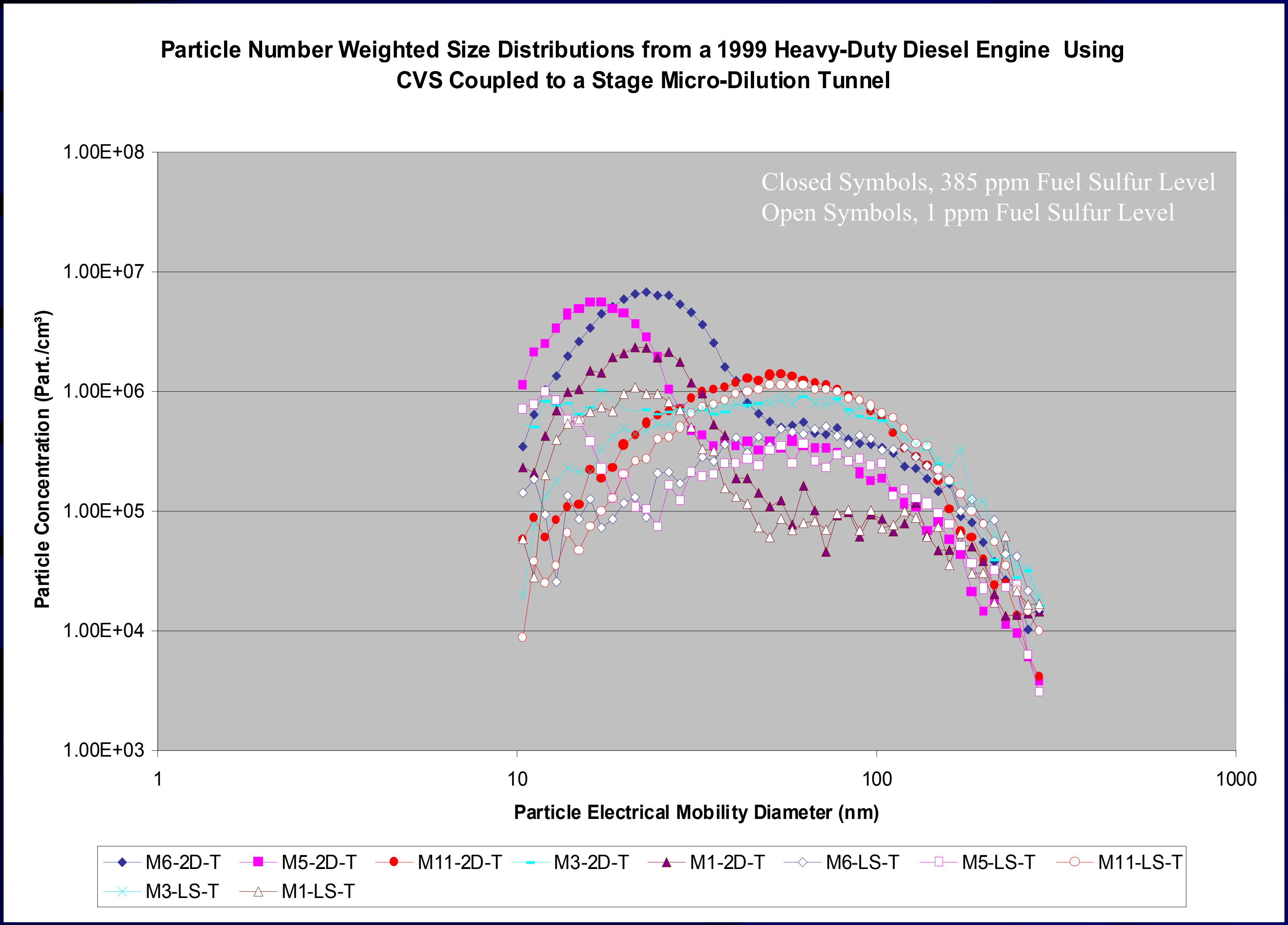


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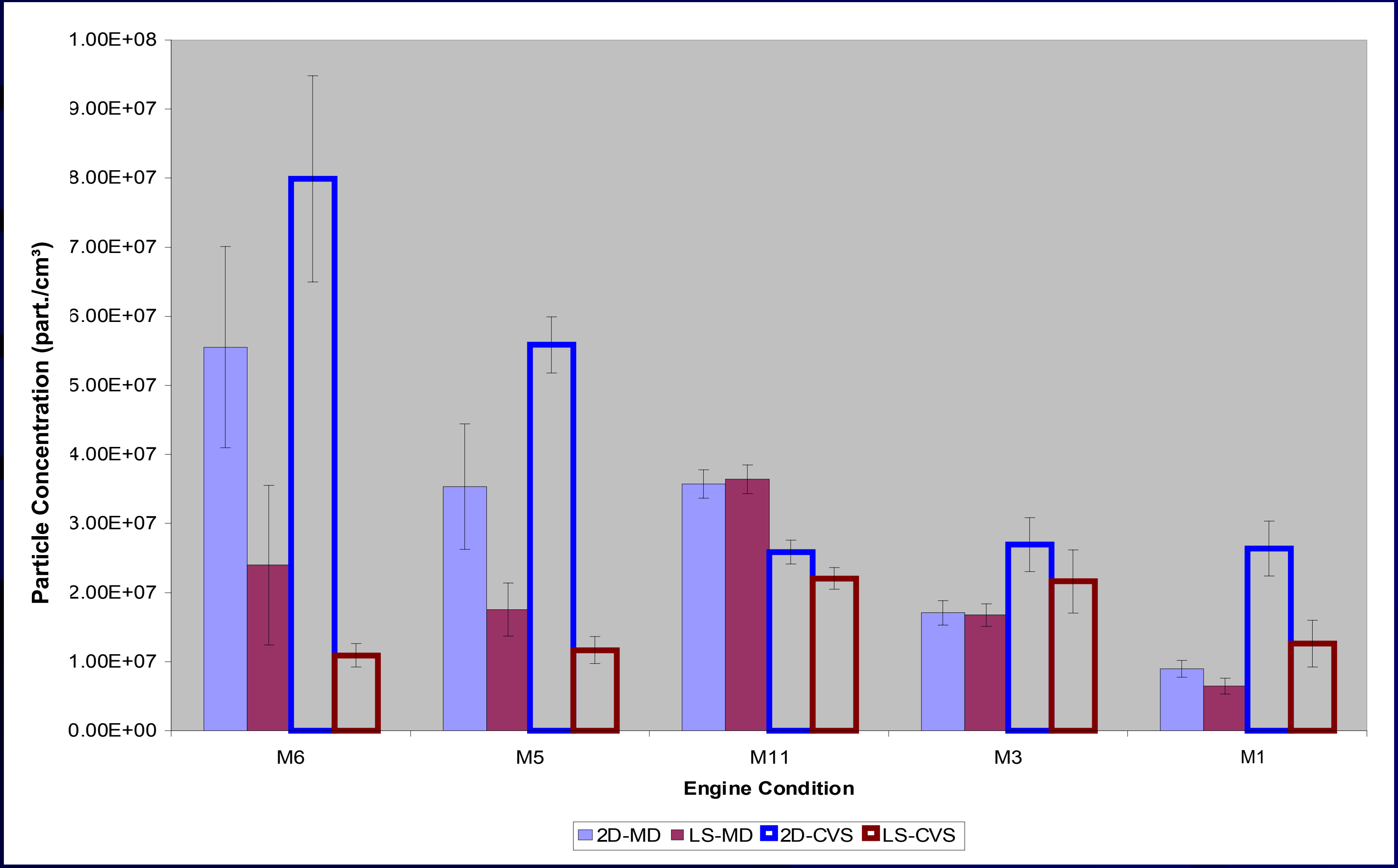
# Particle Number Emission Comparison

(CVS: Constant Volume Sampler, MD: Micro-dilution Tunnel, 2D: US On-highway 385 ppm Sulfur in Diesel Fuel, and LS: 1 ppm sulfur in Diesel Fuel)

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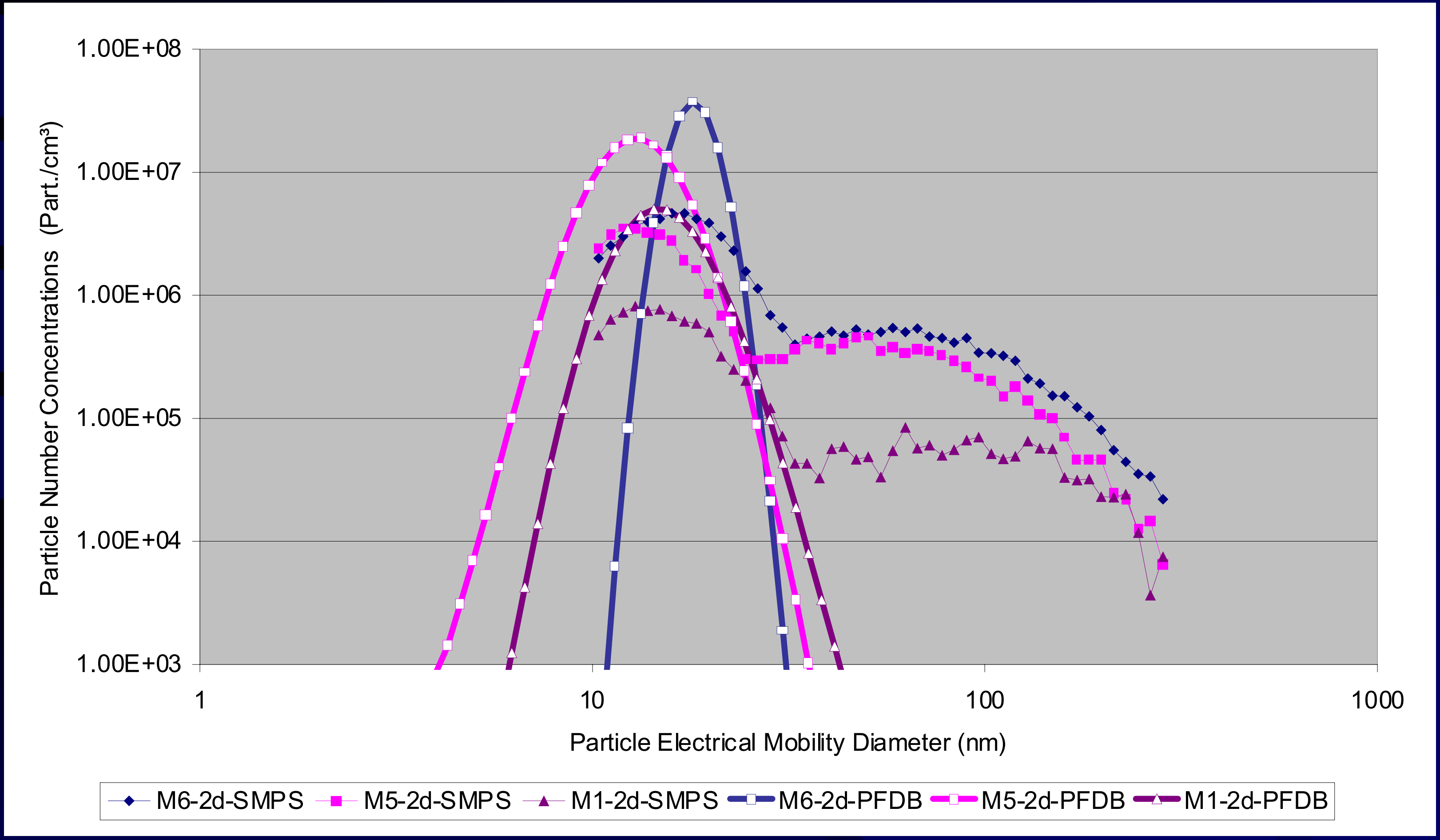
# Performance of PFDB and SMPS For Steady-State Engine Operation (2D fuel)

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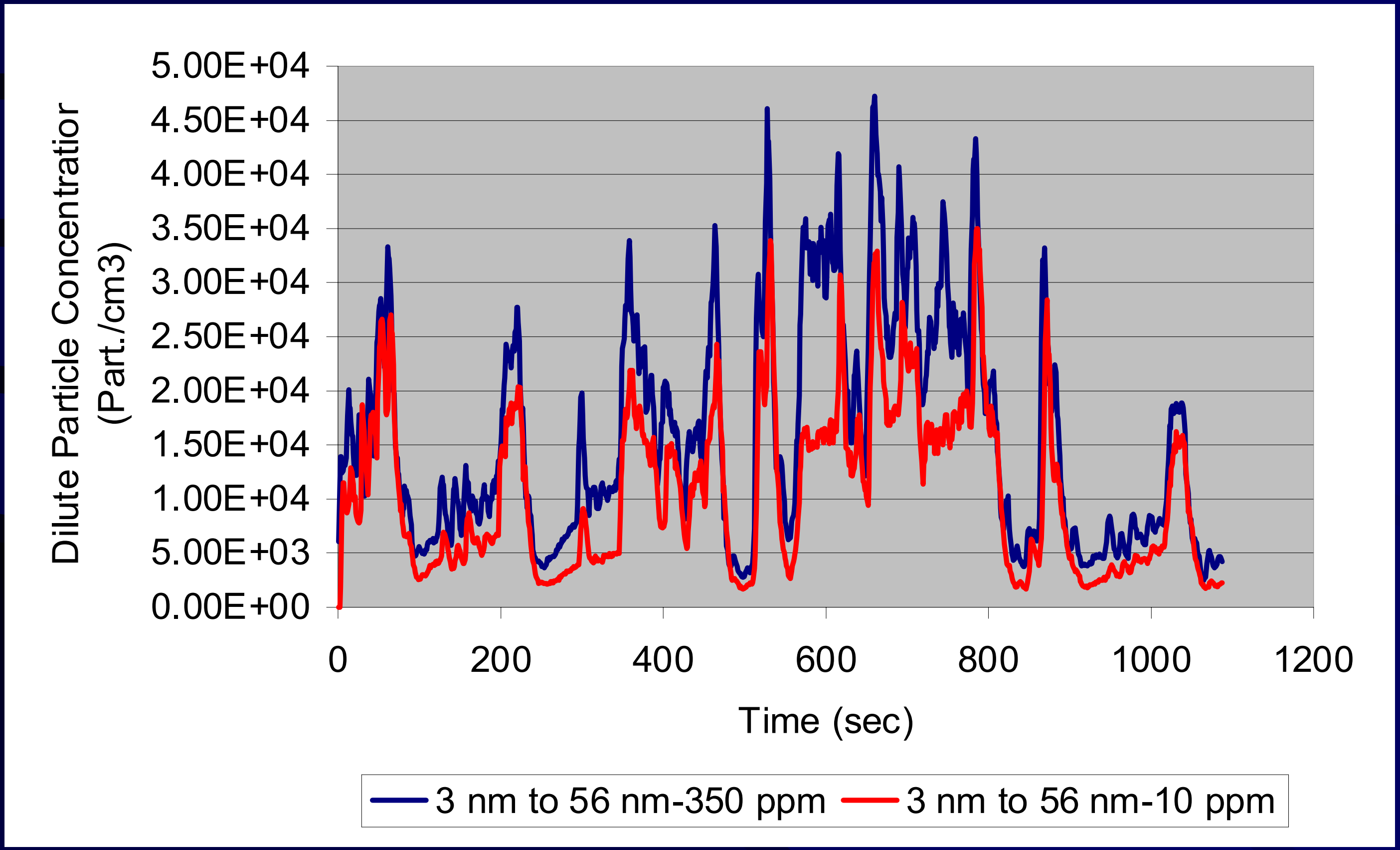
# Nanoparticle Number Changes During FTP Transient Engine Operation Using PFDB (385 ppm and 1 ppm Sulfur Fuel)

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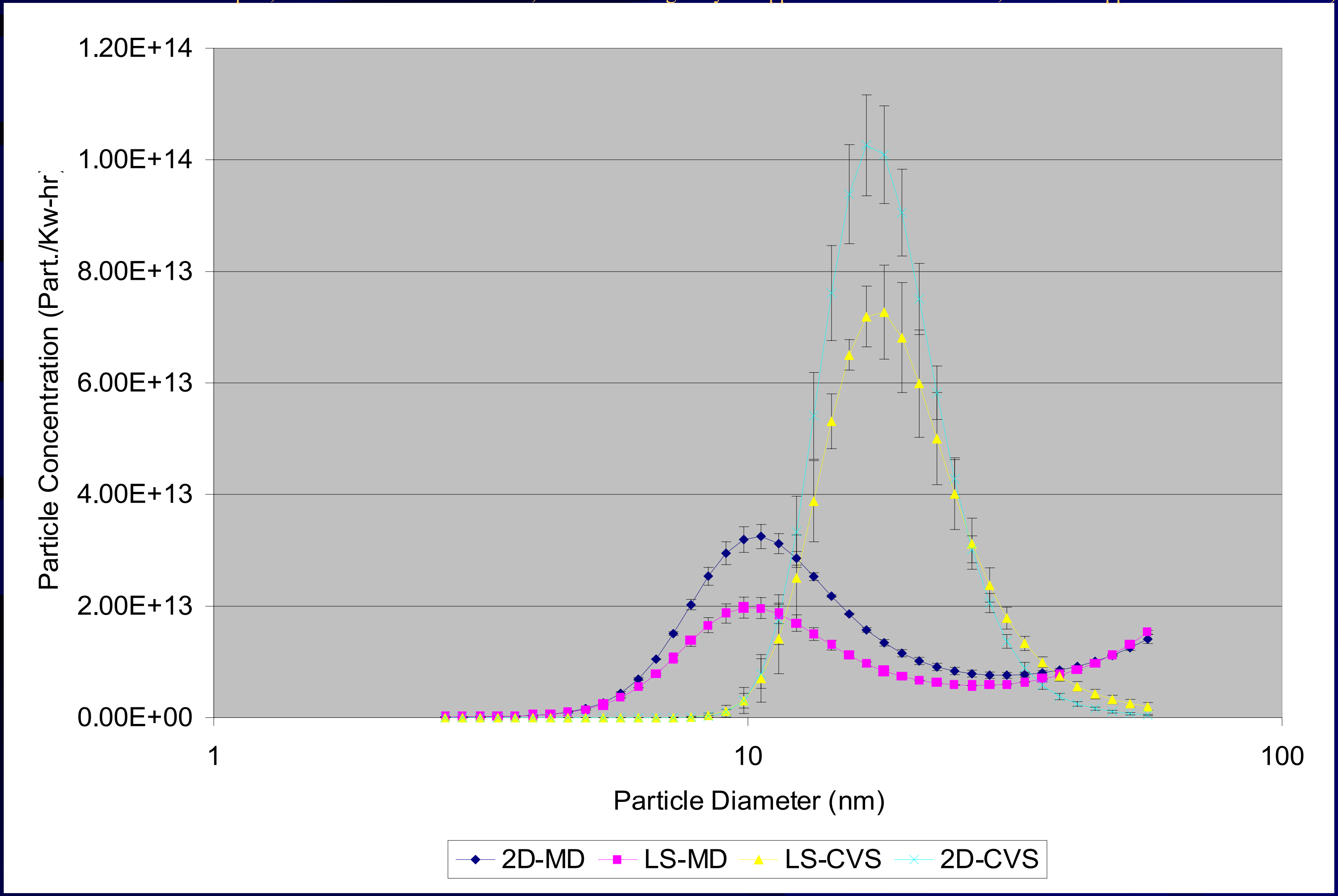
# Average Nanoparticle Number Distribution based on Particle Size Using PFDB during FTP Transient Engine Operation

(CVS: Constant Volume Sampler, MD: Micro-dilution Tunnel, 2D: US On-highway 385 ppm Sulfur in Diesel Fuel, and LS: 1 ppm sulfur in Diesel Fuel)

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# Conclusions

- This work showed the potential of using a PFDB for real time nanoparticle size and number measurements. The diffusion diameter that is measured by the PFDB is the most useful diameter to be used in the nanoparticle size range. Diffusion is the main deposition meachanism in the respiratory tract for nanoparticles ($D_p < 50$ nm)
- The PFDB compared well with the SMPS
- Ultra Low sulfur fuel (1 ppm) showed more than a factor of five reduction in nanoparticle emissions relative to 385 ppm sulfur level.
- The CVS showed higher nanoparticle emission than the micro-dilution tunnel. This was mostly attributed to the dilution process that affects volatile emissions.

# Acknowledgments


- This work was a part of funded particle sizing activities by the US Environmental Protection Agency (EPA). The EPA work assignment managers were Mr. Matt Spears and Mr. Bill Charmley. The work on the development of the PFDB was coordinated with the Particle Technology Laboratory of the University of Minnesota, and with Lovelace Biomedical and Respiratory Research Institute.