



Measuring 2007 Exhaust PM Emissions

Steven H. Cadle

ACES Workshop
Aurora, Colorado
November 6, 2003



Problem Statement

- PM emissions from trap-equipped diesel engines primarily semi-volatiles and condensables
 - Organics (raw and partially oxidized fuel & lubricant)
 - Nitrates
 - Sulfates
- What constitutes the PM mass is operationally defined
- Traditional sampling methods have major limitations
 - Background
 - Artifacts
 - Adsorption of gases
 - Loss of semi-volatiles
 - Chemical reaction
 - Precision/accuracy
 - Insufficient mass for comprehensive analysis



E-66 program

- Anticipated sponsors: CARB, CRC, DOE/NREL, EMA, EPA, SCAQMD
- Contractor: Southwest Research Institute
- In kind support: AVL, Cummins, Horiba, Sensors, Sierra
- Project objectives
 - Conduct a systematic study of variables affecting PM measurement accuracy within the constraints of the 2007 EPA test procedures. Extend the sampling to higher dilution ratios and lower temperatures to better simulate ambient conditions
 - Improve the correlation between full flow CVS PM measurement and partial flow PM measurement
 - Develop a simple alternative to filter mass measurement that can provide data on a timescale of 1 second to 1 minute
- May be opportunities to conduct additional work that supports ACES



Testing

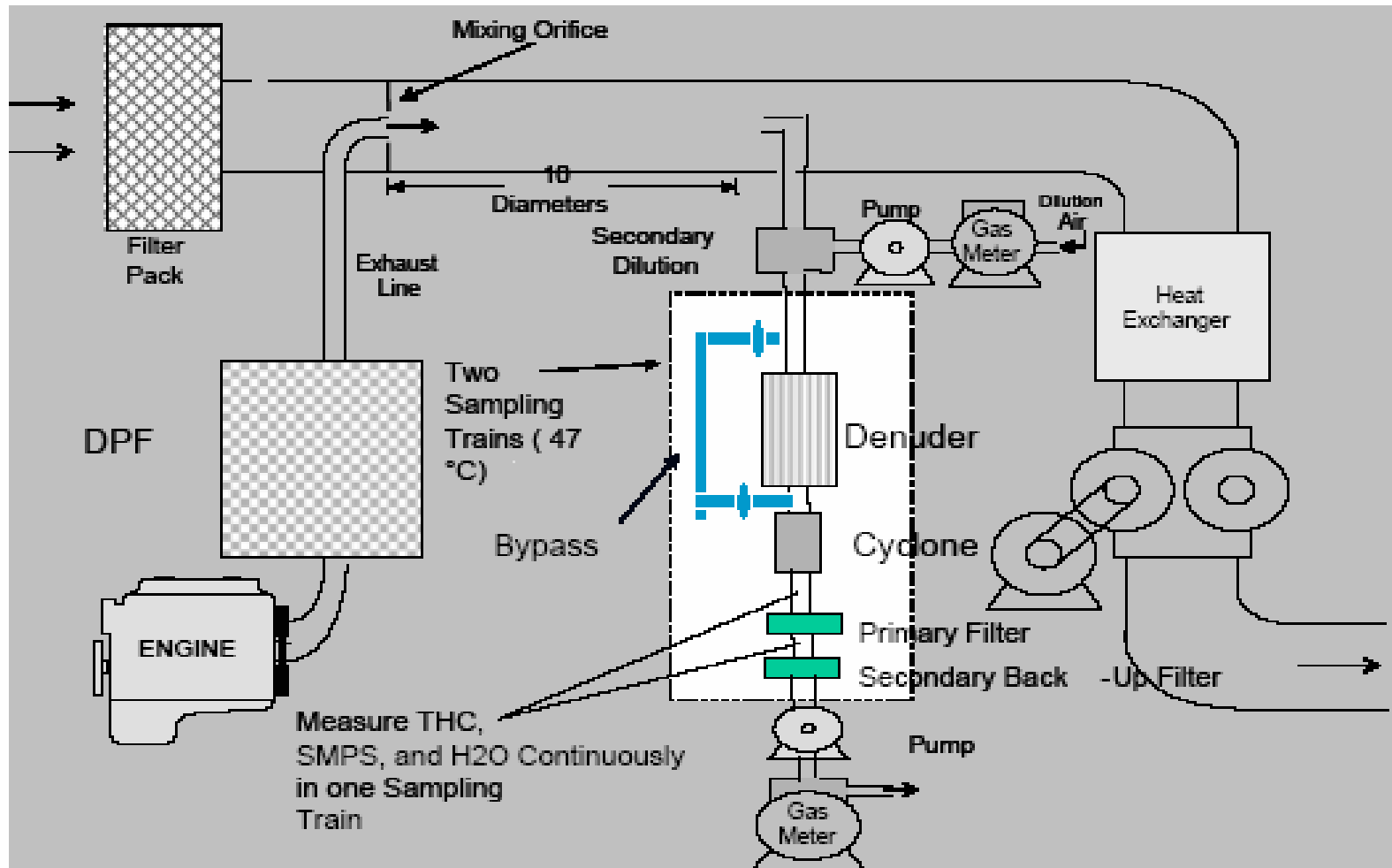
- Engine dynamometer steady-state and transient cycle testing (FTP & ETC) of a 1998 Detroit Diesel, heavy-duty, turbocharged engine
- Catalyzed diesel particle trap
- Low sulfur fuel (other properties to be determined)
- 2007 lubricant



Filter Characterization

- Determine importance of interferences (artifact formation)
 - HC denuder to remove possible adsorbing species
 - Backup filter for losses from filter or penetration (possible use of solid sorbents such as PUF/XAD)
- Filters to be tested
 - TX-40, Zefluor, Teflo, TissueQuartz, Donaldson TF-47
- Chemical analysis to determine interfering species
 - Sulfate, nitrate, chloride, PAH, alkanes, SOF, carbon number distribution for estimation of fuel and lube oil contribution

Experimental Setup for Filter Testing





Sampling Variables

- Filter face velocity and sampling time
 - 10 to 90 cm/sec
 - 40 minutes max time
- Dilution ratio and residence time
 - CVS dilution ratio (constant residence time)
 - Primary dilution ratios 2 to 100
 - CVS dilution ratio and residence time
 - Secondary tunnel dilution ratio
 - Primary DR 2 to 10, secondary 4 to 100
 - Secondary residence time
 - 0.5 to 30 sec
 - Engine and sample system conditioning



Effect of Dilution Geometry on PM

- Partial flow sampling systems and secondary tunnels using different geometries will be run in parallel in a steady-state mode to examine the effect of dilution geometry
- Tunnels
 - SwRI mixing Tee AVL SPC
 - SwRI mixing orifice Cummins tunnel
 - Sierra BG-3 Sensors design (Booker)
 - Horiba MDLT
- Partial flow sampling systems will also be compared to the full flow CVS under steady-state and transient operation



“Real-Time” PM Mass Measurement

- Needed to:
 - Avoid or minimize artifact problems associated with filters
 - Provide higher sensitivity PM measurements than practical with filters
 - Provide real-time data useful for understanding transient operation and PM trap regeneration
- Methods:
 - Booker quartz crystal microbalance (QCM)
 - TSI long and nano-scanning mobility particle sizer (LN-SMPS)
 - SwRI solid particle measurement system (SPMS)
 - Dekati mass monitor (DMM)
 - TSI engine exhaust particle sizer (EEPS)
 - Sunset Laboratory semi-continuous EC/OC



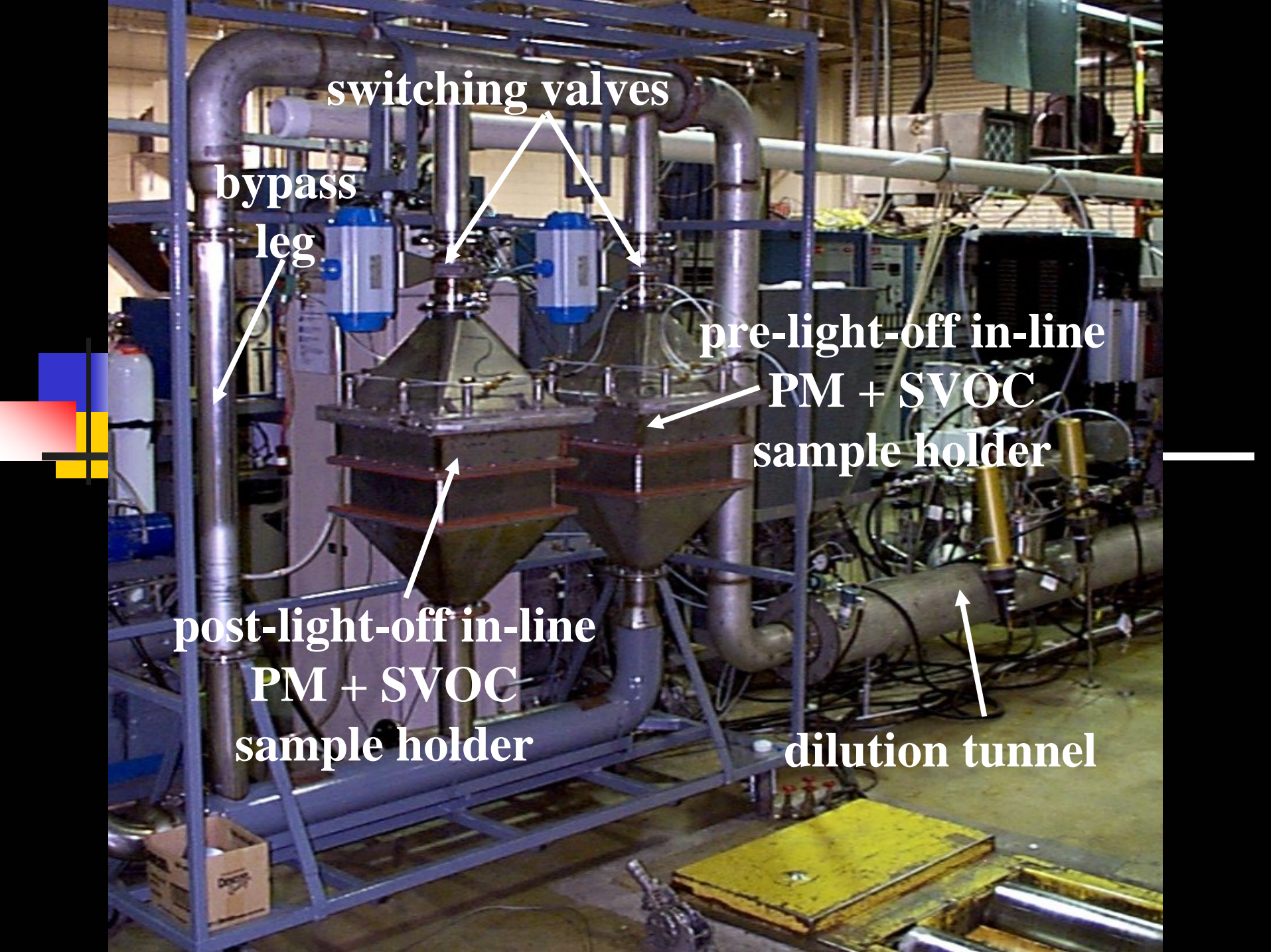
Additional Tasks

- Comparison of filter mass using filter face temperatures of 25 ± 5 °C and 47 ± 5 °C
- Determine the effect of filter equilibration time on filter mass
- Studies on a CNG engine to determine applicability of recommended methods to other exhaust sources
- Determine the effect of exhaust NO_2 on the concentration of nitro-PAHs using a NO_x denuder ahead of the sample filter
- Additional chemical characterization of the collected PM
- Detailed chemical composition of the fuel and oil



Issues Not Addressed in This Study

- Effect of sample times > 40 minutes on PM mass and composition
- Impact of atmospheric conditions on PM composition (high dilution, low temperature, humidity)
- Particulate nitrate loss during sampling
- Collection of gas phase semi-volatiles
- Impact of trap regeneration on PM composition
- Impact of NO_x aftertreatment methods on PM mass and composition
- Composition as a function of particle size
- Recovery of PM from filters



switching valves

bypass
leg

pre-light-off in-line
PM + SVOC
sample holder

post-light-off in-line
PM + SVOC
sample holder

dilution tunnel



Conclusion

- The E-66 program is expected to provide guidance on how best to sample trap equipped HDD exhaust PM for mass determination, chemical characterization and in-vitro studies
- Since the program is just starting and has an 18 months duration there may be opportunities to address additional important issues