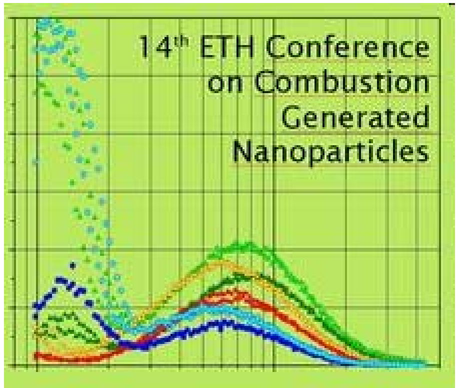

Real time measurements of ash particle emissions

David Kittelson, David Gladis, and
Winthrop Watts

UNIVERSITY OF MINNESOTA
Driven to Discover℠

Outline

- Introduction and background
- Results
  - Tests performed
    - Lube oil spray calibration experiments
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    - Transient ash measurements
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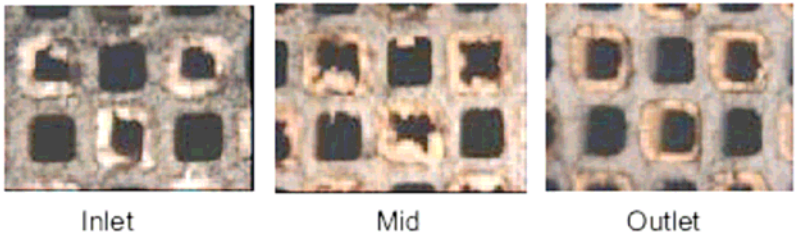
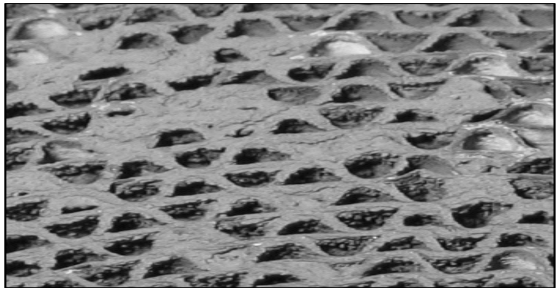
Why do we care about ash emissions?

- Degradation of exhaust aftertreatment systems
  - Deposition in Diesel particulate filters (DPF)
  - Plugging exhaust catalysts
- Health concerns with metallic nanoparticles
  - Diesel or SI
  - Mainly a concern for engines without exhaust filters
- Relationship with lube oil consumption

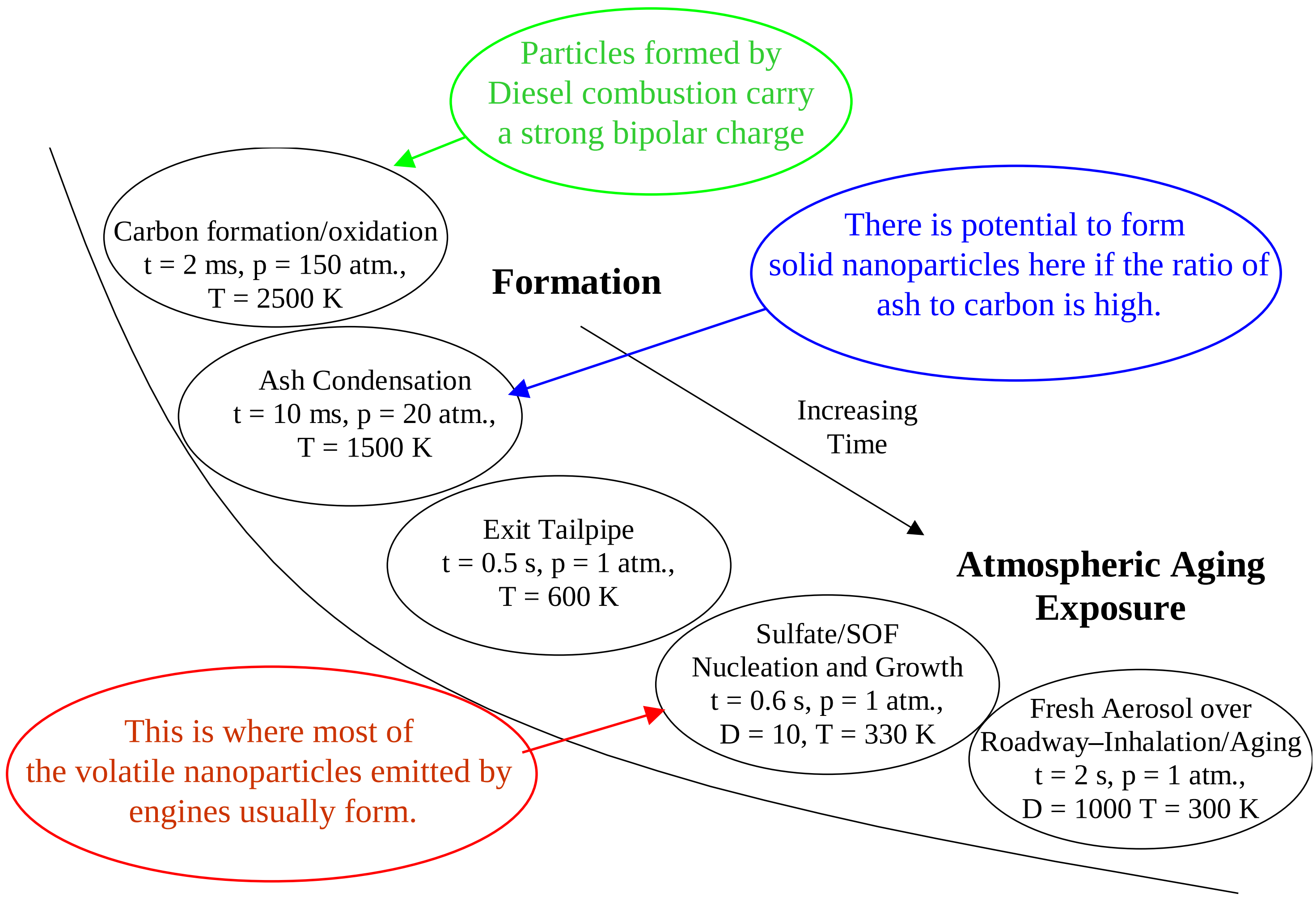


Ash distribution in exhaust filter channels (Helbel and Bhargava, 2007)



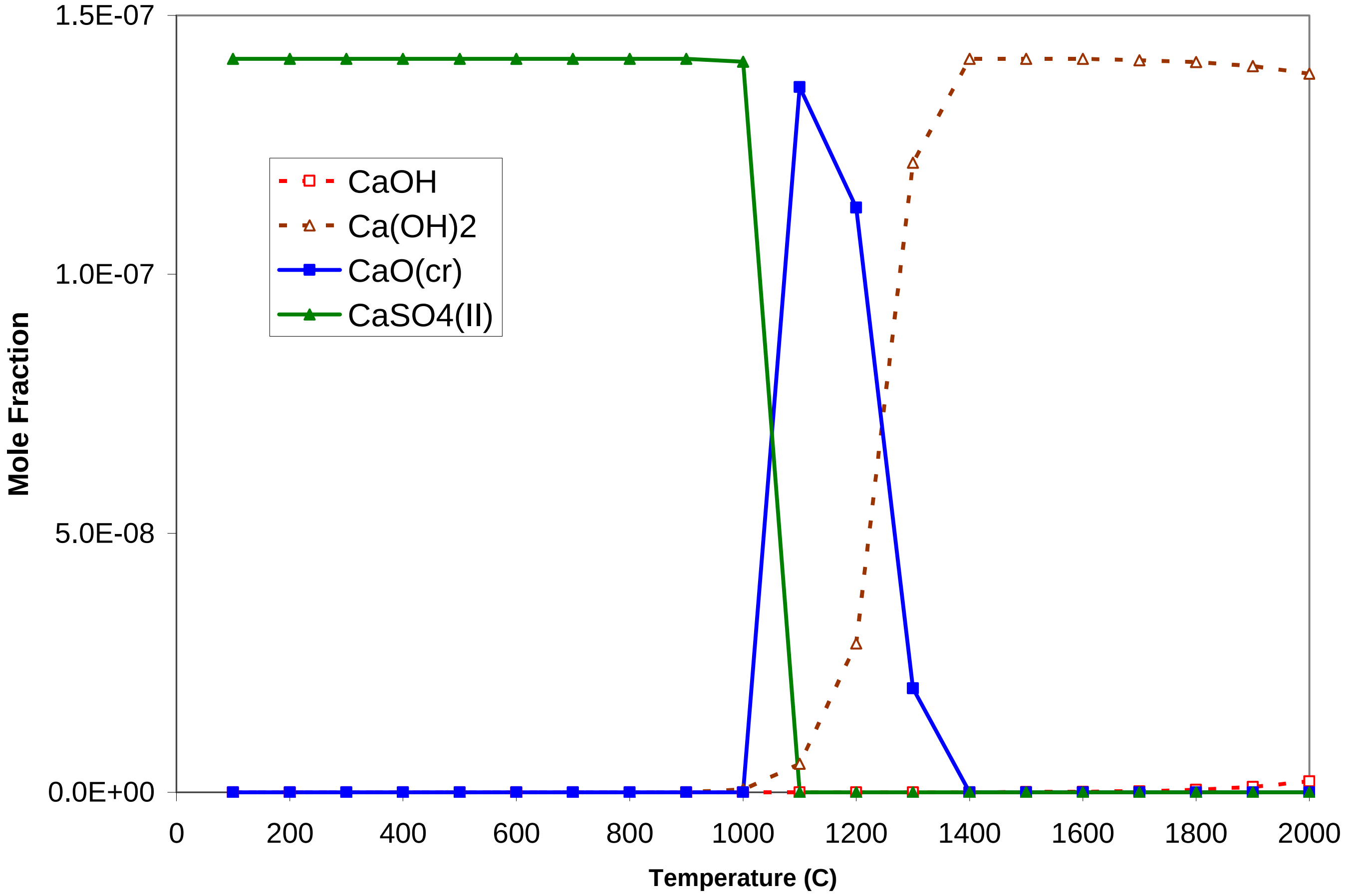
Accumulation of poorly crystalline Mn_3O_4 *on the face of a TWC (Hayhurst, et al., 2006)*

Particle formation history – 2 s in the life of an engine exhaust aerosol



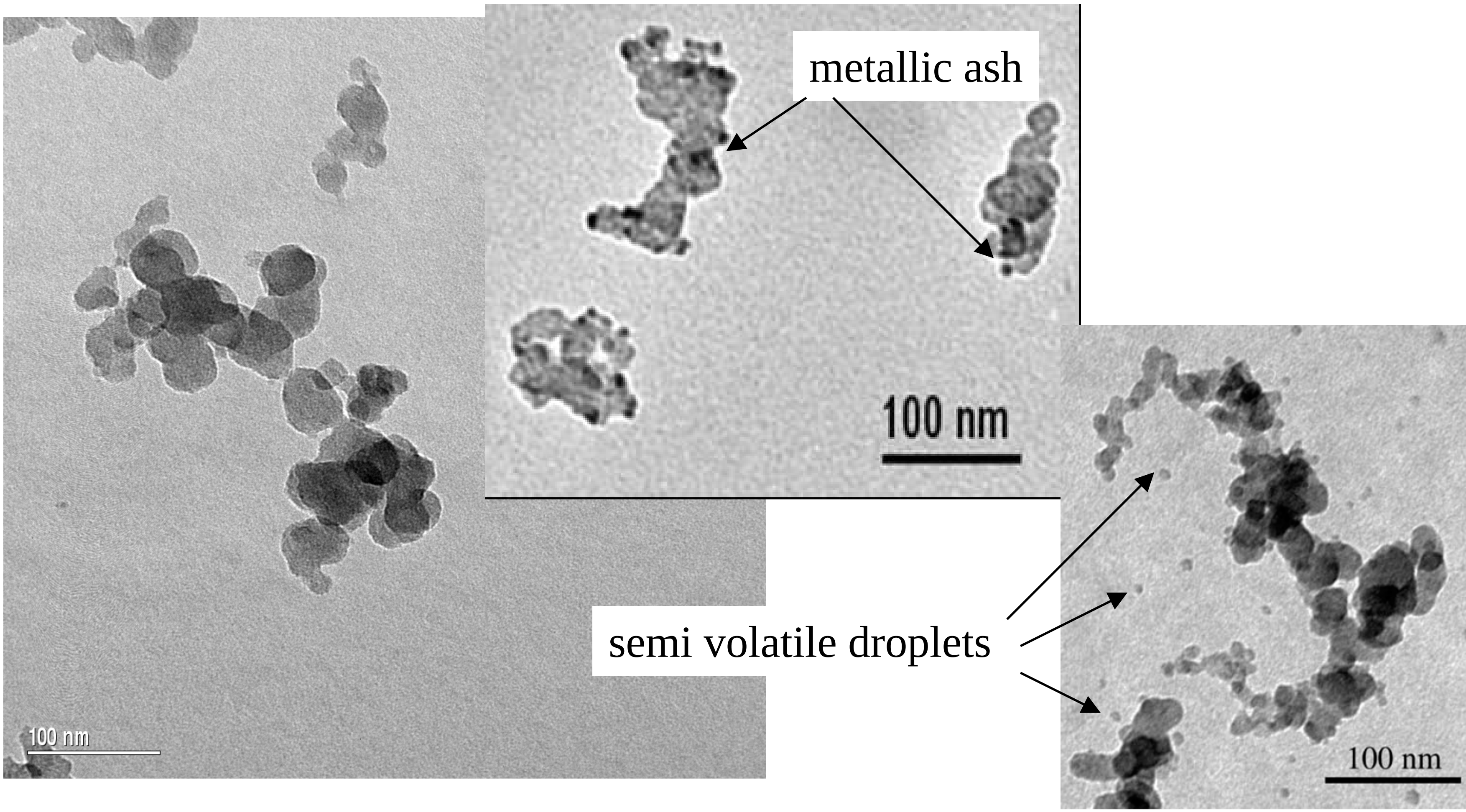
Kittelson, D. B., W. F. Watts, and J. P. Johnson 2006. "On-road and Laboratory Evaluation of Combustion Aerosols Part 1: Summary of Diesel Engine Results," Journal of Aerosol Science 37, 913–930.

Predicted equilibrium distribution of calcium compounds in diesel engine exhaust



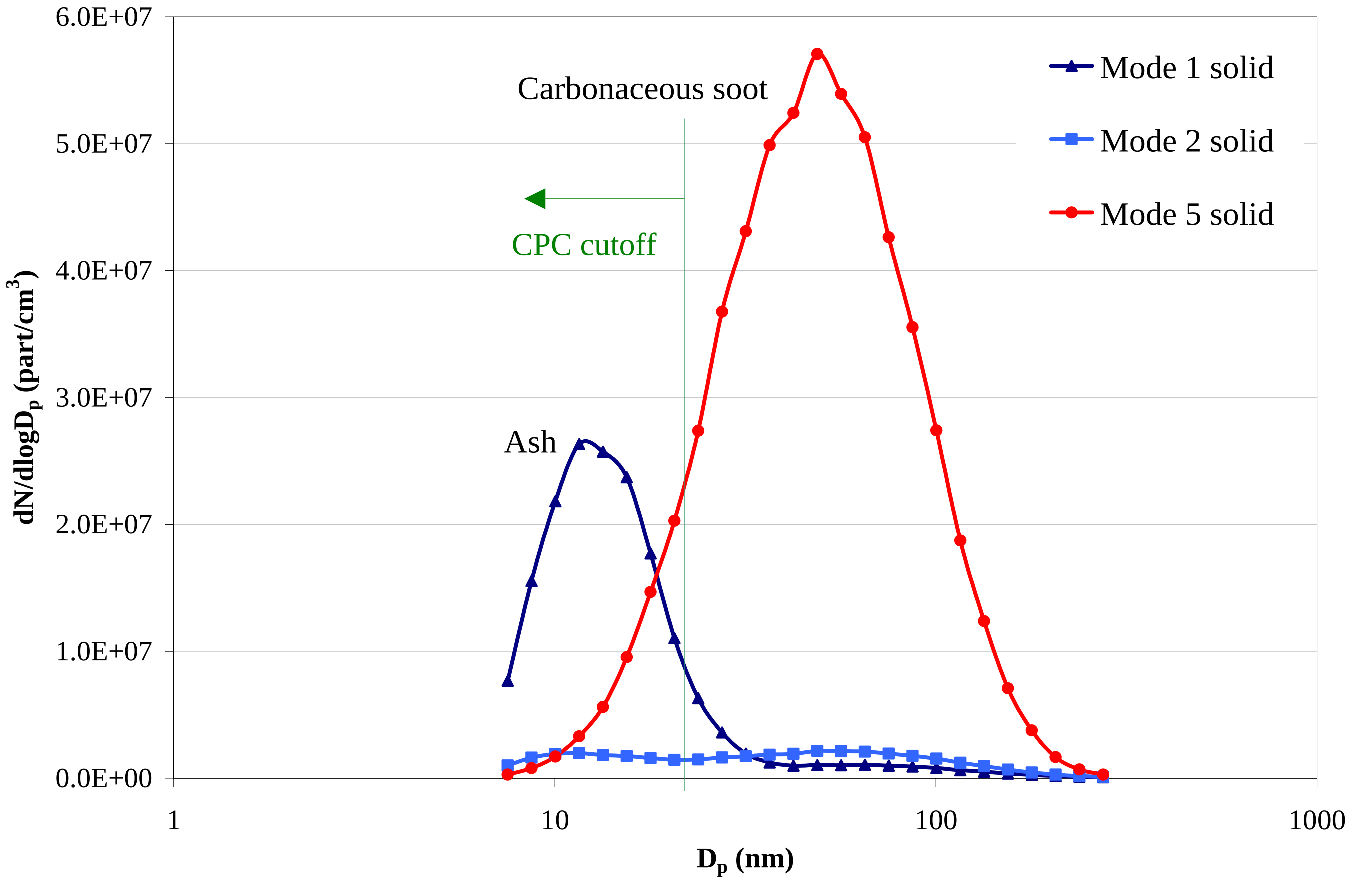
Assumptions: 50 ppm sulfur fuel, equivalence ratio 0.5, lubrication oil containing 5000 ppm Ca, oil consumption 0.1% of fuel consumption.

Ash particles typically “decorate” the surface of soot particles but may also nucleate independently



Without Exhaust Aftertreatment

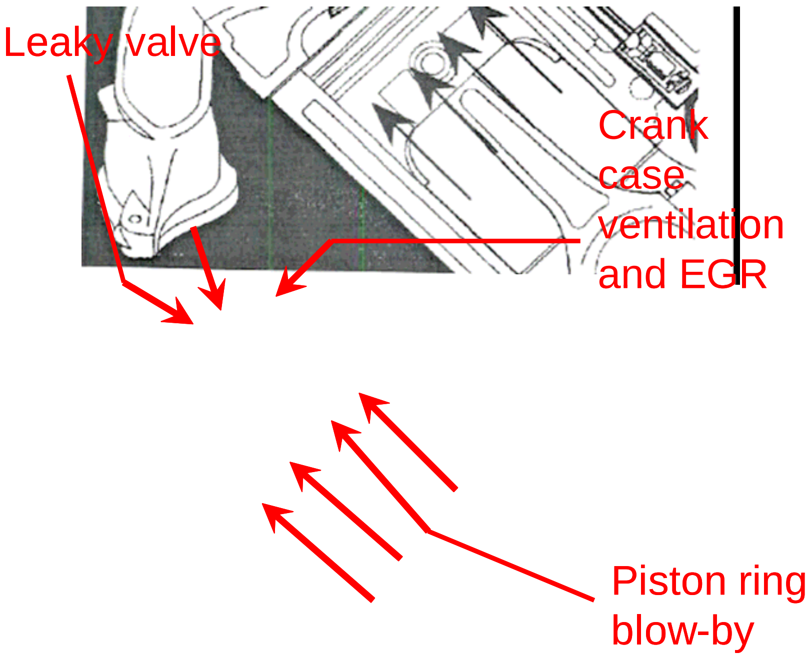
Engine out, light-load, low soot conditions: Most of the number emissions are solid with Dp < 23 nm



Cummins 2004 ISM engine, BP 50 fuel, AVL modes

Lube oil consumption leads to ash emissions

- Sources: mostly lube oil additives, engine wear, fuel additives
- Principle ash constituents: Ca, Zn, Mg, Fe, P, S



Modified from Hill et al., (1991)

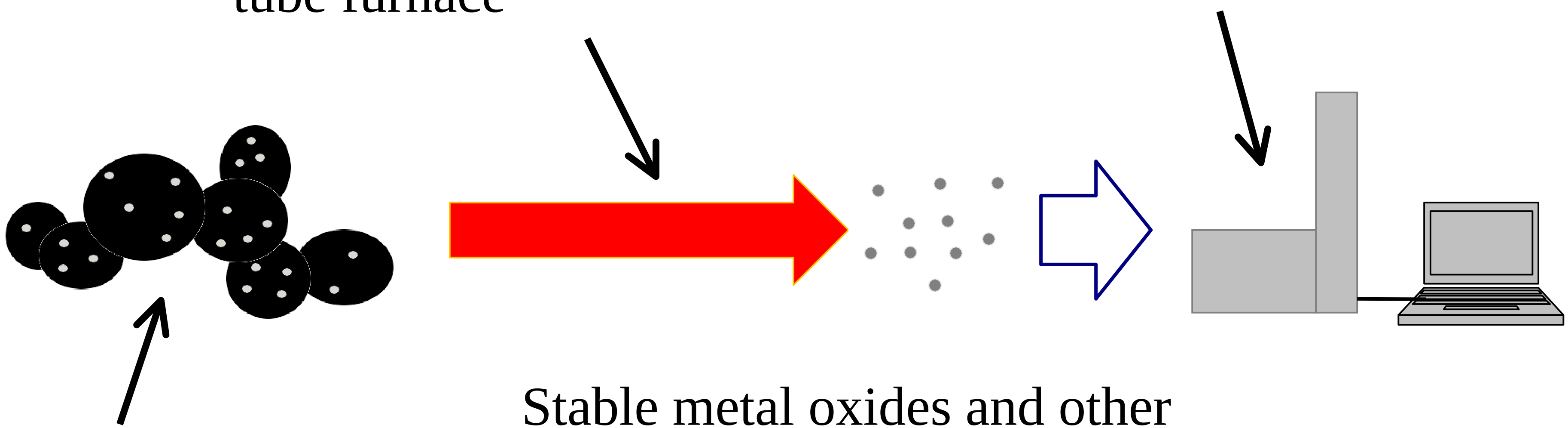
Objectives

- To develop and validate a real-time method to measure engine ash emissions
  - Testing the sensitivity of measurement method to specific metallic lube oil constituents
  - To validate the method for steady-state and transient Diesel engine emission application

High temperature oxidation method (HTOM) overview

Oxidize soot and HC PM within high temperature tube furnace

Cooled particles measured using real/near-real time particle instruments



Diesel exhaust or other metallic ash containing aerosol

Stable metal oxides and other refractory metal compounds are formed or survive high temperature tube furnace

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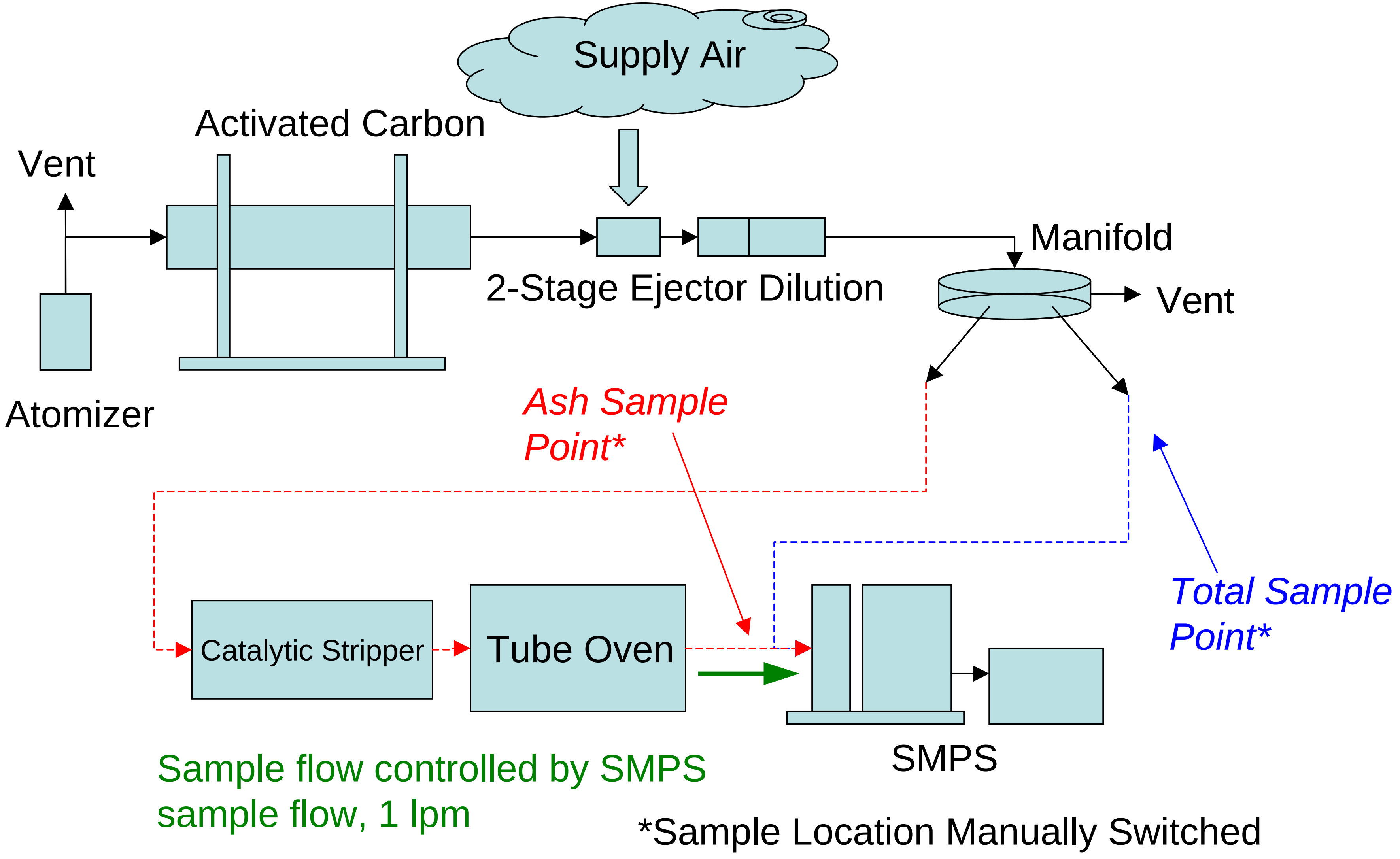
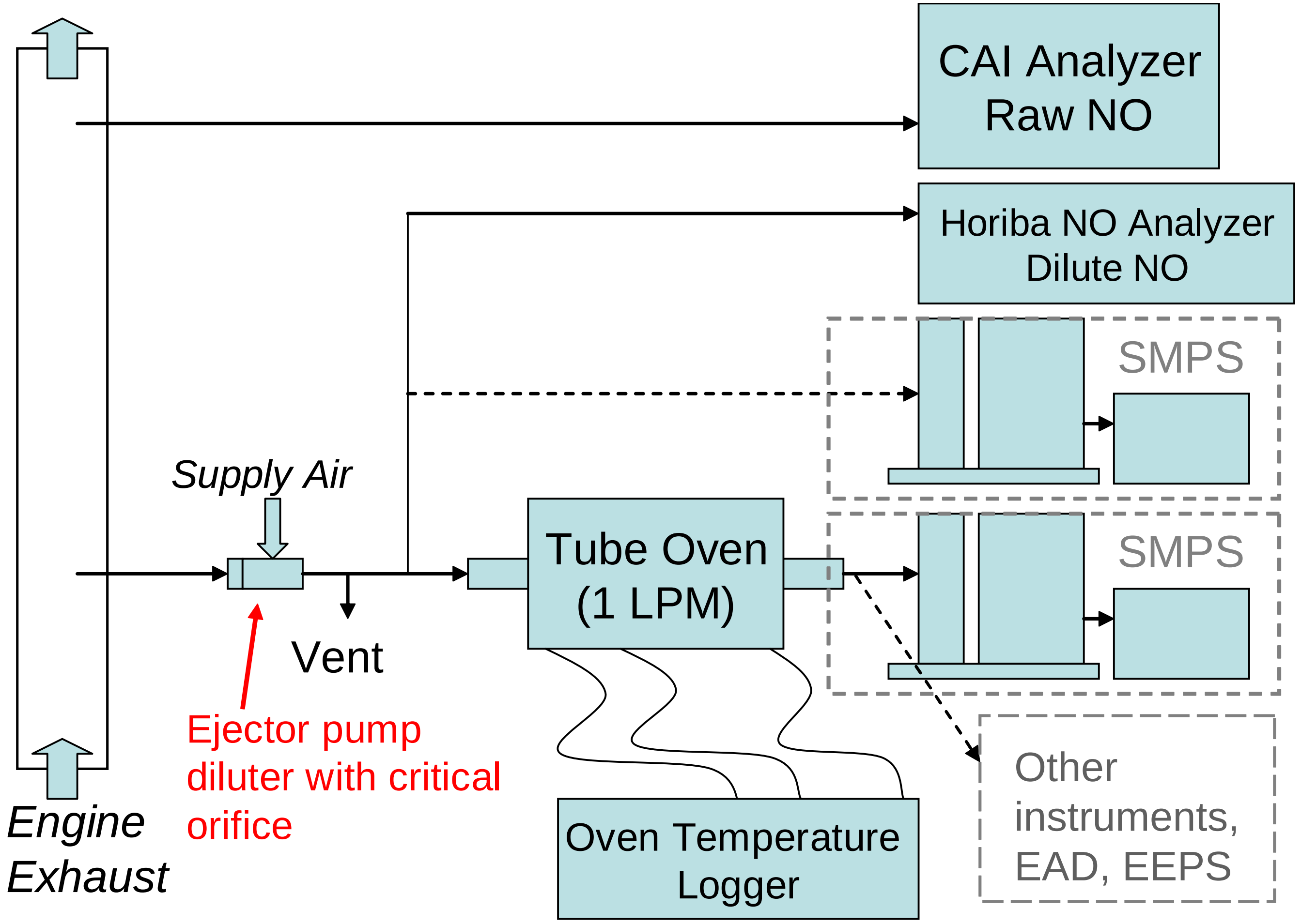
Lube spray apparatus



Engine exhaust apparatus



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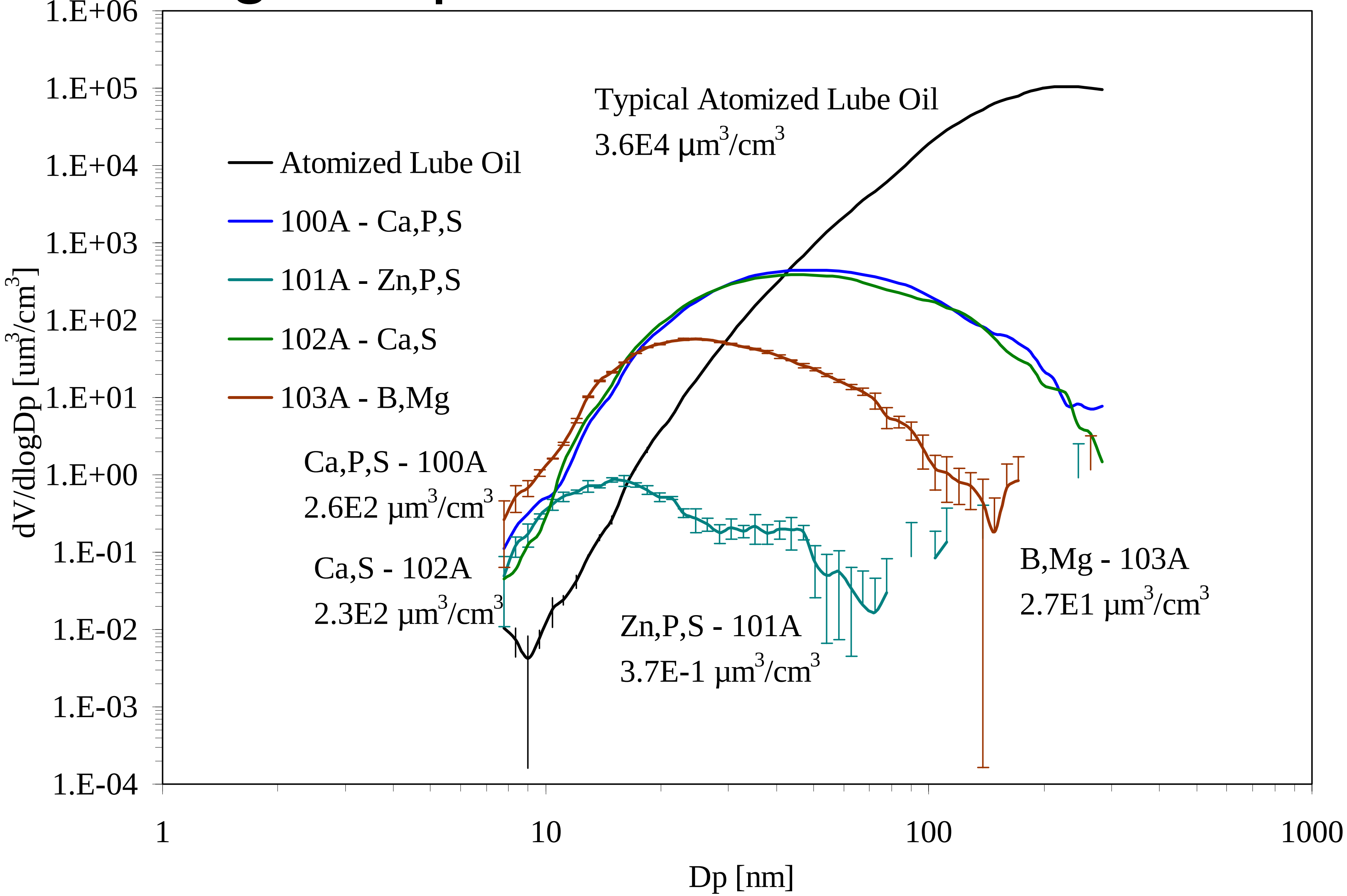
Lube oil spray calibration experiments

- Investigate high temperature stability of likely ash constituents
- Atomize specially formulated lubricating oils with different additive packages
- Measure particle size distribution upstream and downstream of the furnace
  - Determine penetration vs. temperature
  - Compare with expected solid ash fraction

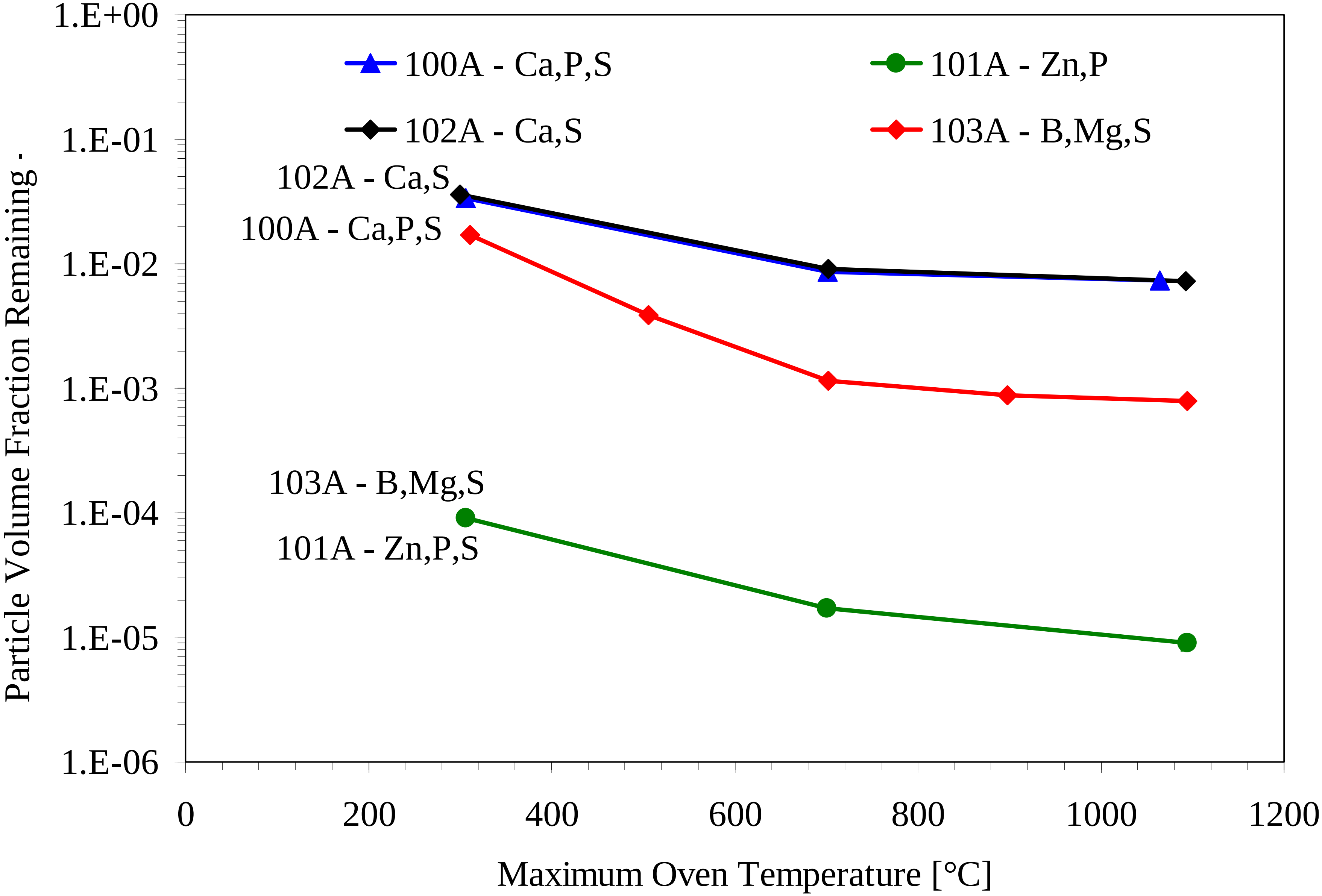
Specially blended lubricants provided by Castrol

	Base stock	Metal mass fractions in ppm			
	104A	101A	100A	103A	102A
B	<5	<5	<5	285	<5
Ca	<2	<2	3946	<2	3724
Mg	<2	<2	8	~500	<2
P	2	976	1052	<10	13
S	55	1998	802	57	8804
Zn	<5	1008	<5	<5	<5

Upstream and downstream volume weighted particle size distributions



Particle volume fraction penetrating the tube oven



Expected metallic mass compared to measured

				Metallic Volume Fraction		
Blend #	Element	Compound	Concentration [ppm]	Expected	Measured	Measured/Expected
100A	Ca	$CaCO_3$	3946	2.9E-03	7.3E-03	2.51
101A	Zn	$ZnSO_4$	1008	5.9E-04	9.6E-06	0.02
102A	Ca	$CaSO_4$	3724	3.4E-03	7.2E-03	2.10
103A	Mg	$MgCO_3$	500	5.3E-04	7.8E-04	1.48

Note: Expected concentrations are based on the assumption of spherical particles of the compounds listed

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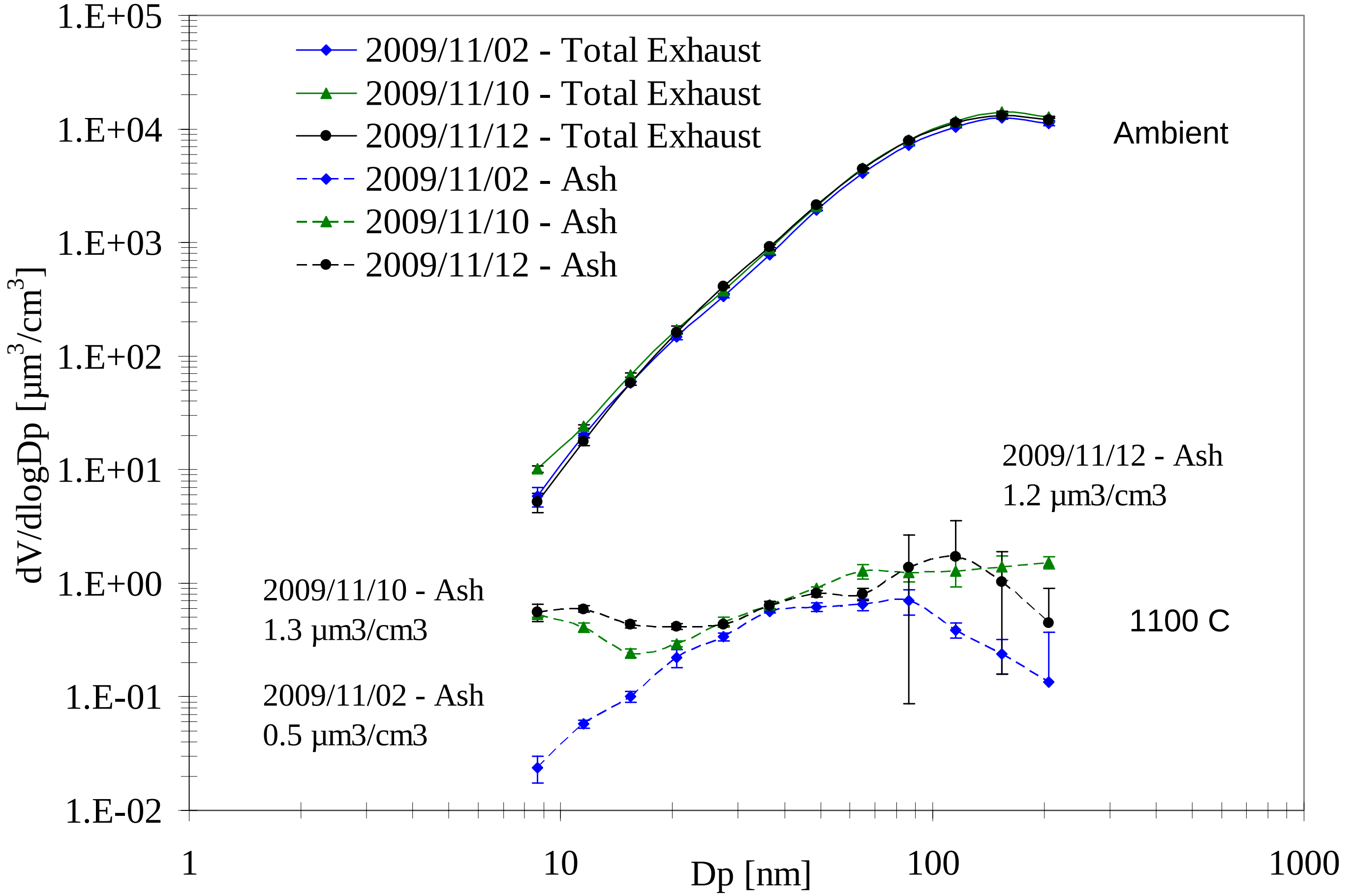
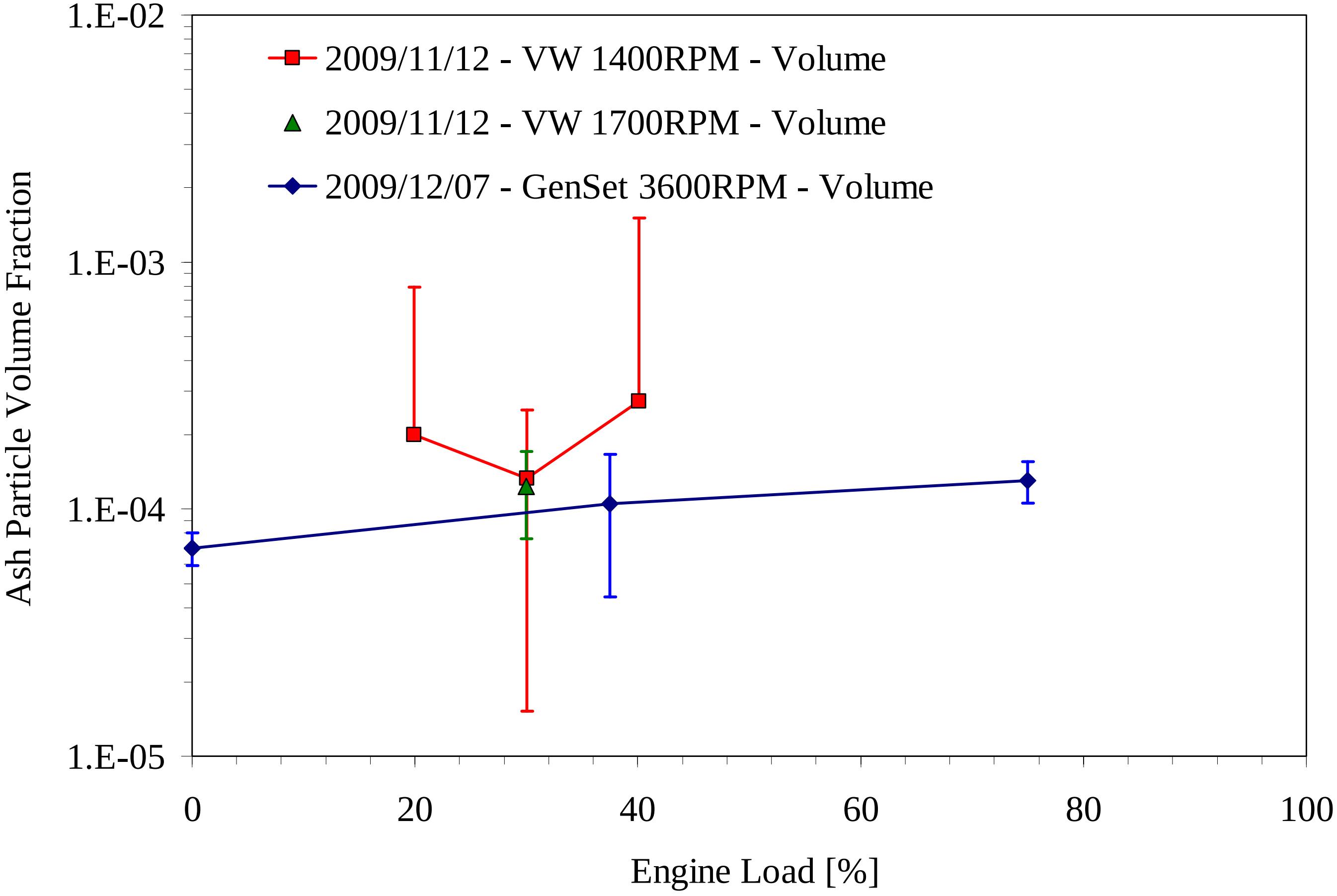
Volume weighted particle size distributions from VW TDI engine



Ash volume fraction of exhaust particles for different engine conditions



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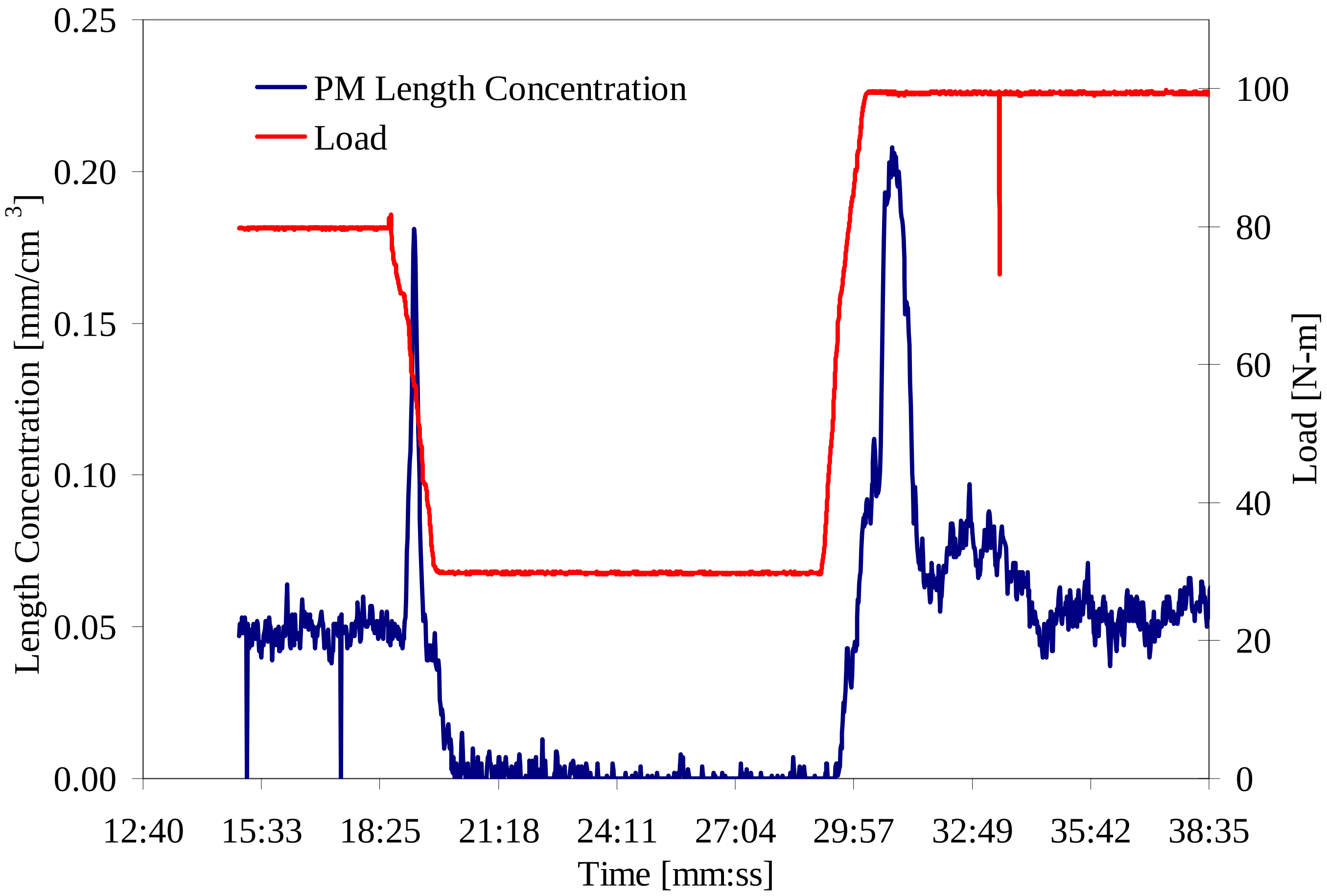
Transient engine ash emissions



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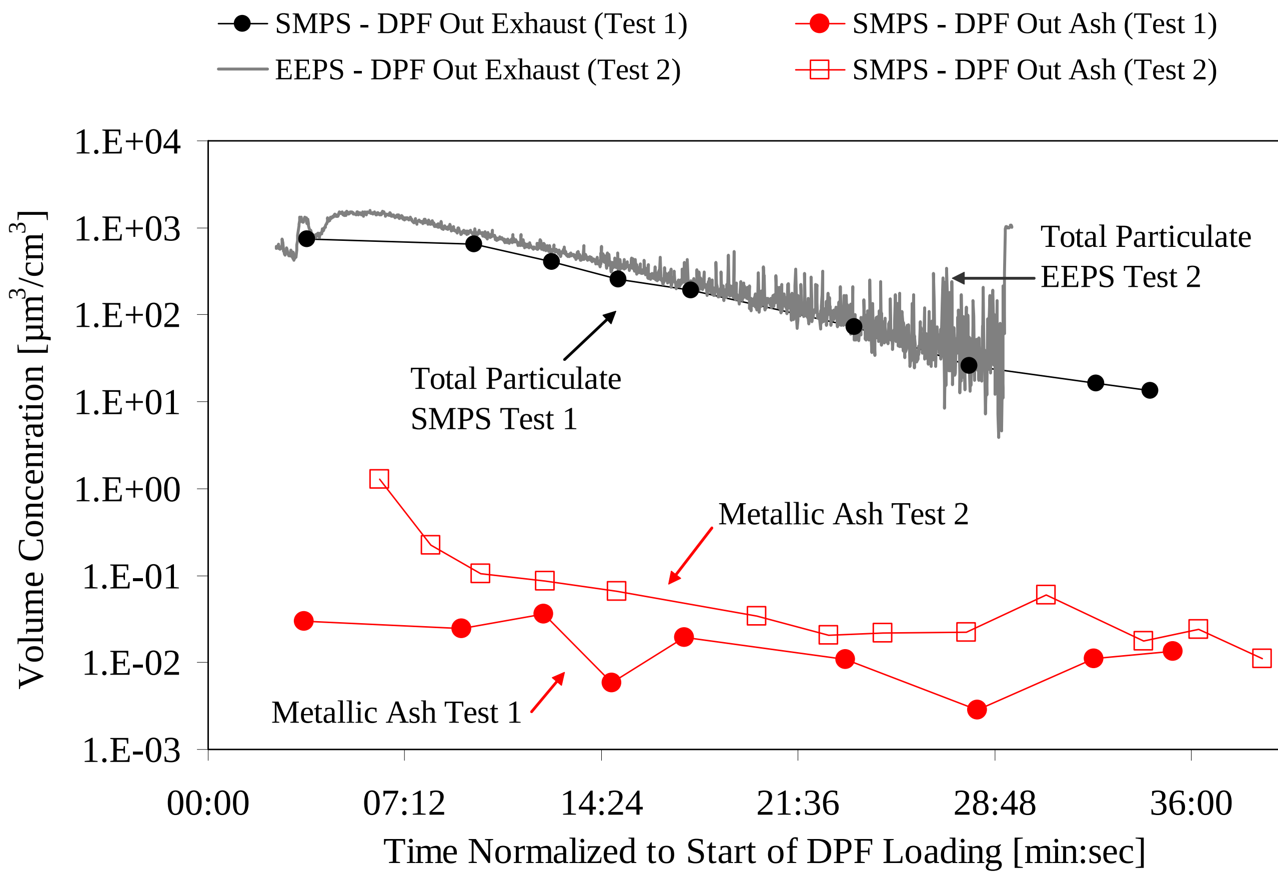
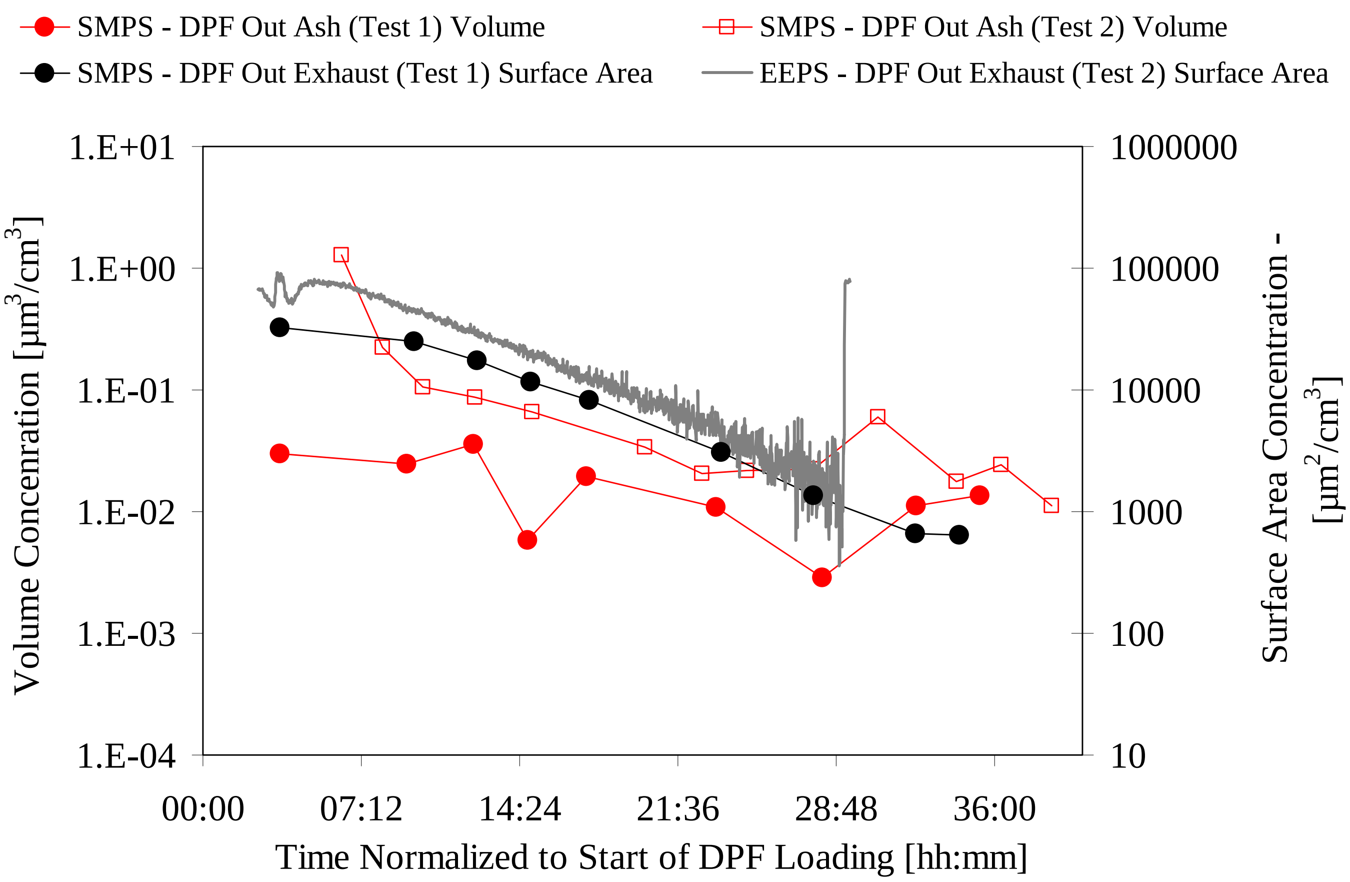
Soot and ash particle volume concentration downstream DPF



Soot surface area and ash volume concentrations downstream DPF



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Conclusions

- HTOM calibration experiments lube oil sprays showed that
  - Ash constituents of Ca and Mg additives were conserved
  - Expected Zn compounds were not found – apparently due to formation of volatile materials lost to the walls
  - This suggests possible different deposition mechanisms within a DPF
- Steady-state ash measurements showed a slight increase of ash fraction of exhaust particles with load
- Ash emissions under changing engine conditions were highly transient and history dependent
- Ash volume concentrations were successfully measured downstream a loading DPF and were shown to track better with soot surface area than volume concentration
- Ongoing work includes TEM analysis and ATOFMS analysis of particles treated by HTOM

Acknowledgements

- We wish to acknowledge the generous support of this work by contributions from BP-Castrol and Corning

- Thank you for your attention

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Volume weighted particle size distributions from Cummins APU