Particle Generator for Engine Exhaust Simulation

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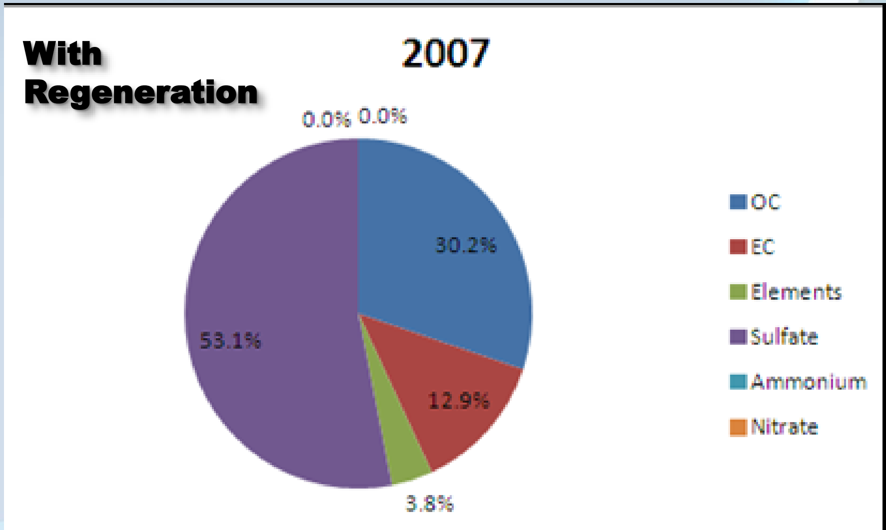
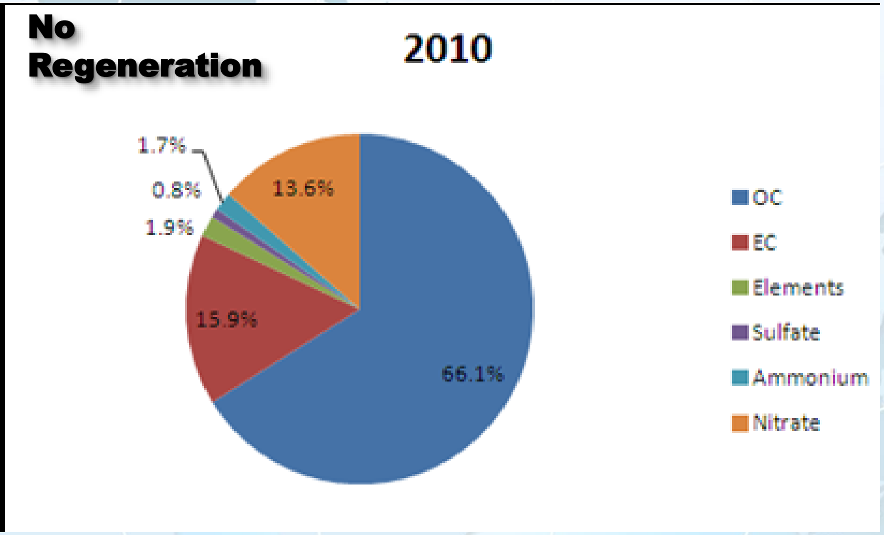
Particulate Matter Composition in Modern Highway Engines

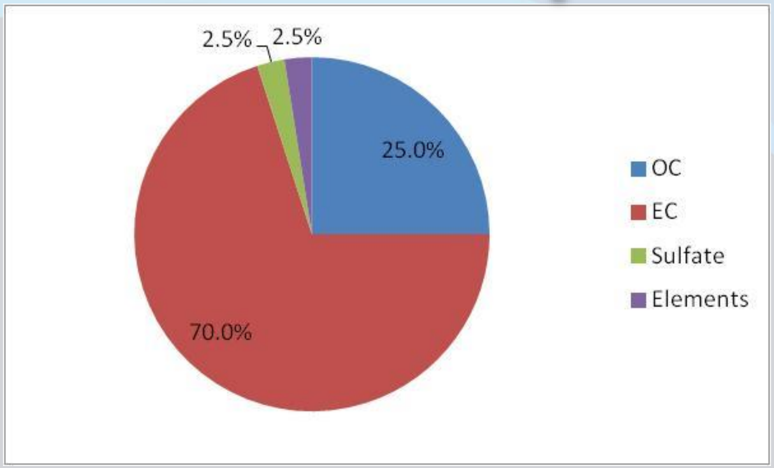
2007: Diesel with DPF



2010: Diesel with DPF+SCR



Gasoline Direct Injection



Engine exhaust aerosol composition is a mixture of organic and inorganic species and elemental carbon

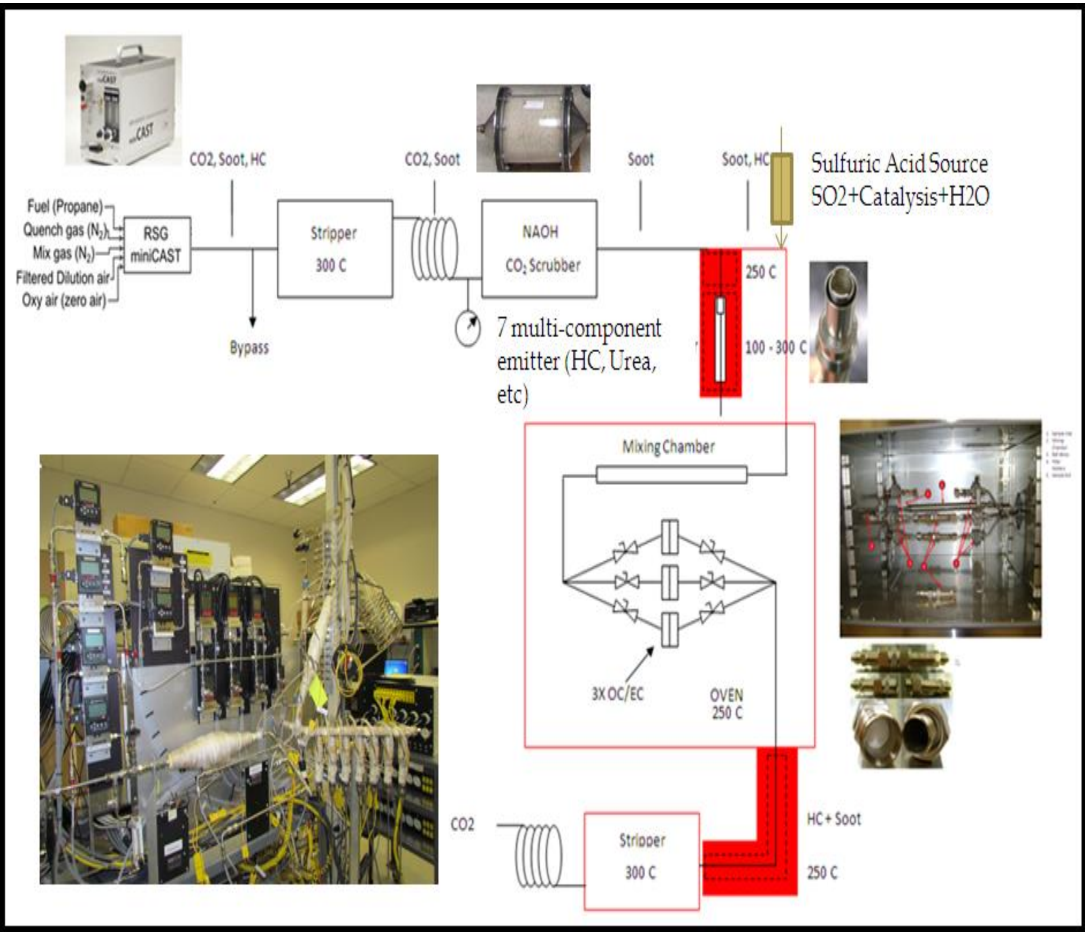
Particle Generator Development

- **Objectives**
  - Develop a "quiet" particle generator that can simulate engine exhaust aerosol composition for different combustion sources:
    - Soot or elemental carbon
    - Particle phase hydrocarbons
    - Sulfuric acid
    - Elements
    - Urea/ammonia
    - Others
  - Use the generator to better understand
    - Particle Instrument Calibration
    - Particle formation and growth
    - Losses in sample lines and artifacts formation
    - Aftertreatment system poisoning effects
    - Particle morphology
  - Use the generator to improve the particle sampling method in terms of:
    - Particulate matter mass
    - Particle Number; e.g. look at the feasibility of refining the sampling system for total (solid + volatile) particle number

The Particle Generator
(Housed in SwRI Nanoparticle Laboratory)

Features

- Elemental Carbon or Soot
  - Min-CAST + Catalytic Stripper
- HC Source
  - Developed a HC generator
  - Controlled C16 to C42 (alkanes for now but flexible to add any other compounds)
  - Concentration range: 0 to 100 ppmC
  - CO2 for hydrocarbon detection
- Sulfuric Acid Source
  - SO2 + catalytic stripper + H2O
  - Concentration range: 0 to 100 ppm
  - SO2 for H_2SO_4 detection
- Other Sources like, urea, ammonia and can be easily added to the system



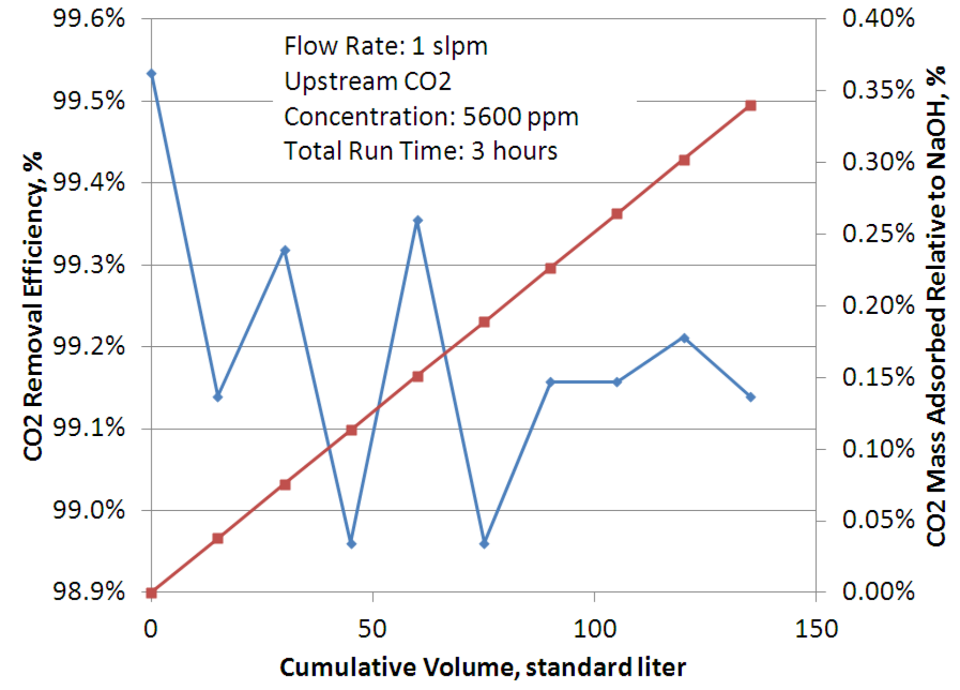
Elemental Carbon + 7 Hydrocarbons (C1-C42) + H_2SO_4+NH3

High Efficiency Sodium Hydroxide CO2 Scrubber

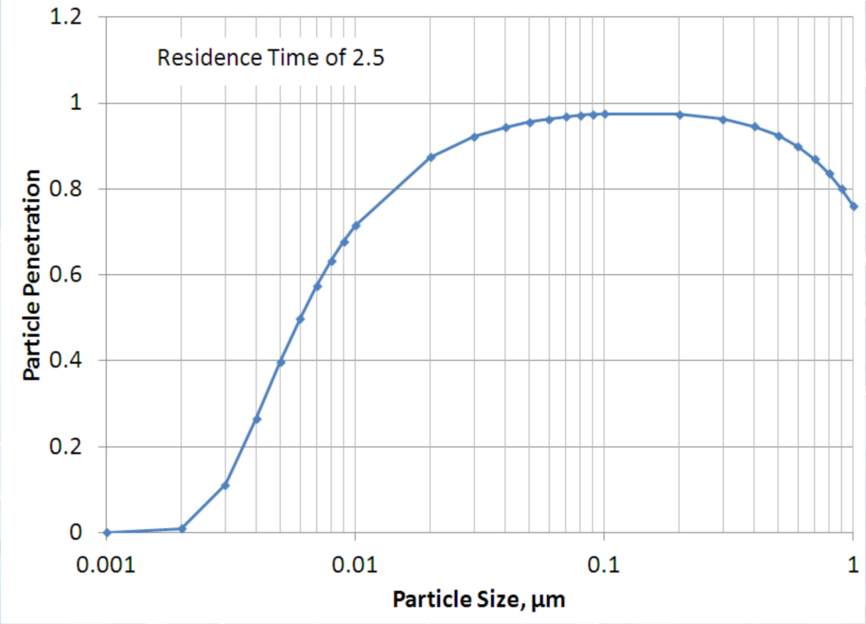
$CO_2 + H_2O \rightarrow H_2CO_3$

$2NaOH + H_2CO_3 \rightarrow Na_2CO_3 + 2H_2O$

CO2 Removal



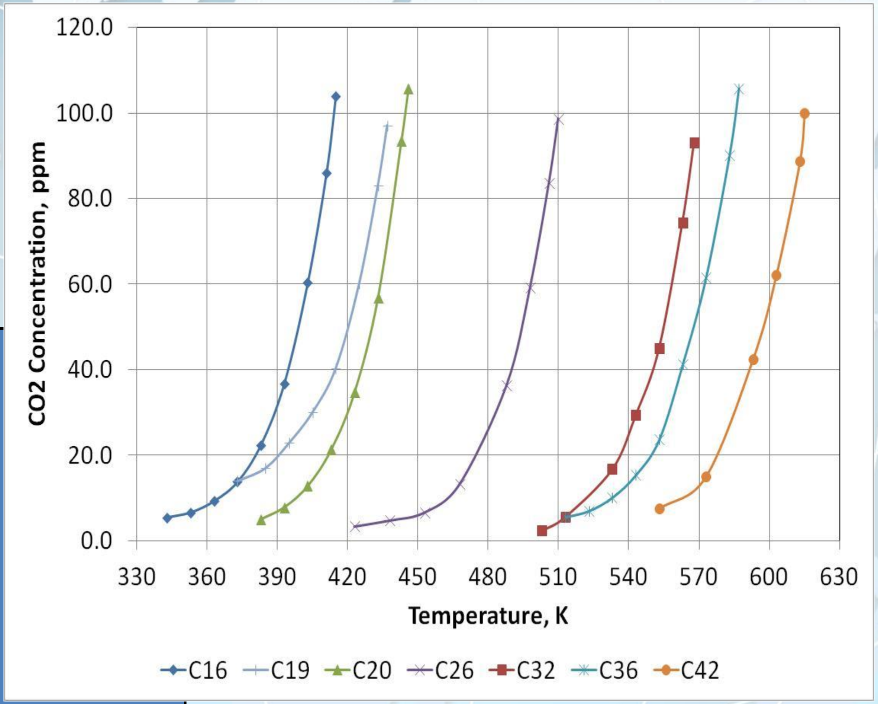
Particle Penetration (Theory)



We were able to design a very high efficiency CO2 scrubber with acceptable Particle Loss

Generating Different Hydrocarbon Profiles Using CO2 as Tracer

HC Mass Concentration Range from 0 to ~ 60 mg/m^3



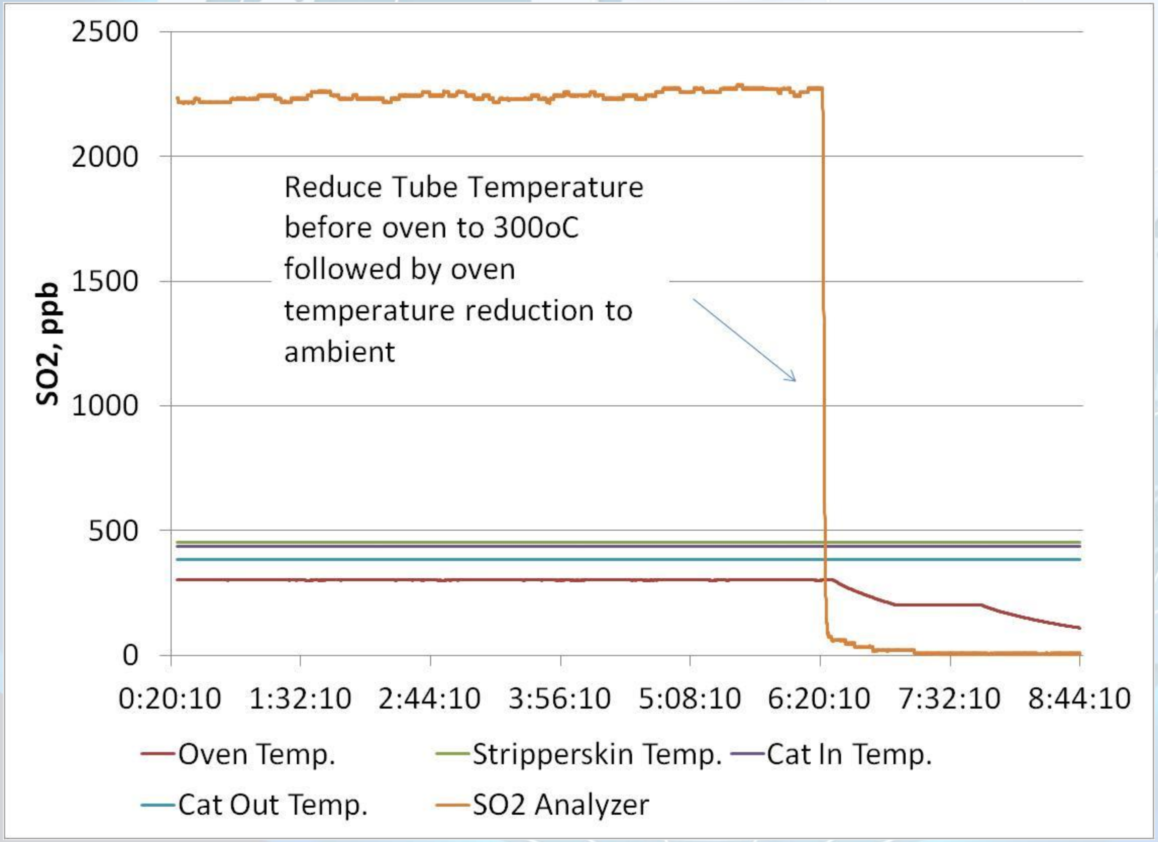
	Measured	CO2-Based	% Difference
	mg/m³	mg/m³	
C16	16.74	17.20	2.7%
C20	28.82	29.85	3.6%
C26	29.45	29.50	0.2%
C32	34.95	34.66	-0.8%
C36	31.48	29.82	-5.3%
C42	26.45	21.62	-18.3%
Measured:	Weight Difference before and after		
CO2-Based:	Based on CO2 Measurement Downstream of Catalytic Stripper		

HC was transported at 250°C
Catalytic Stripper was operated at 300°C
The system seems to suggest losses of C42 at temperature of 250°C

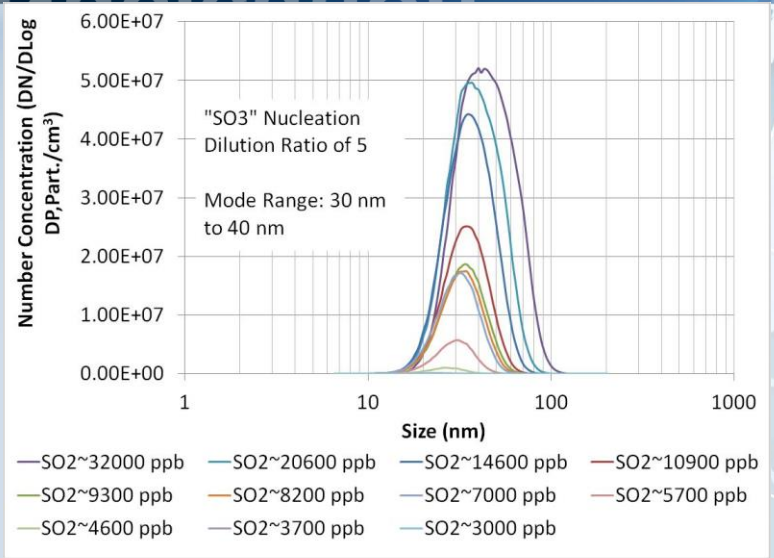
Higher stripper temperature and sample line temperature give a better recovery even for C42

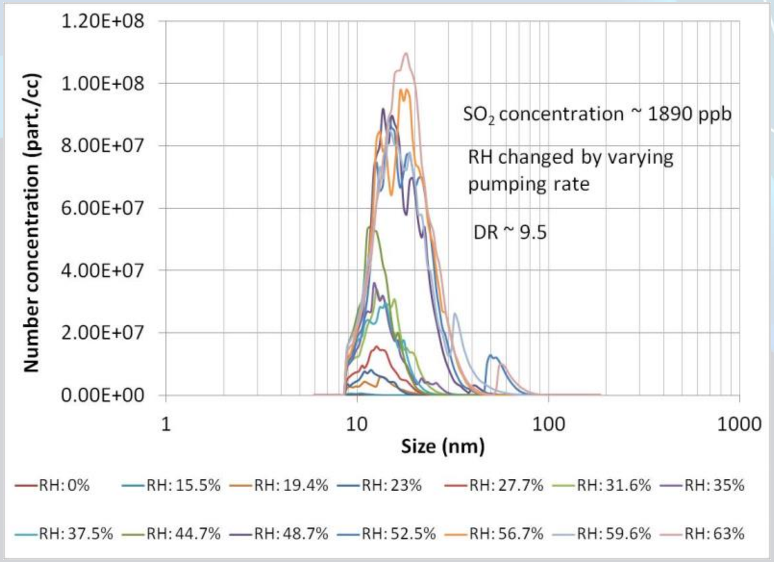
Complete Loss of SO3 with Oven Temperature Down to Ambient

- At 1100°C, we were able to decompose 95% of the SO3-SO4 formed
- The literature suggests a temperature of 1250°C is needed for complete decomposition (*Noglik et a., J. of Solar Energy Engineering, 2009)*



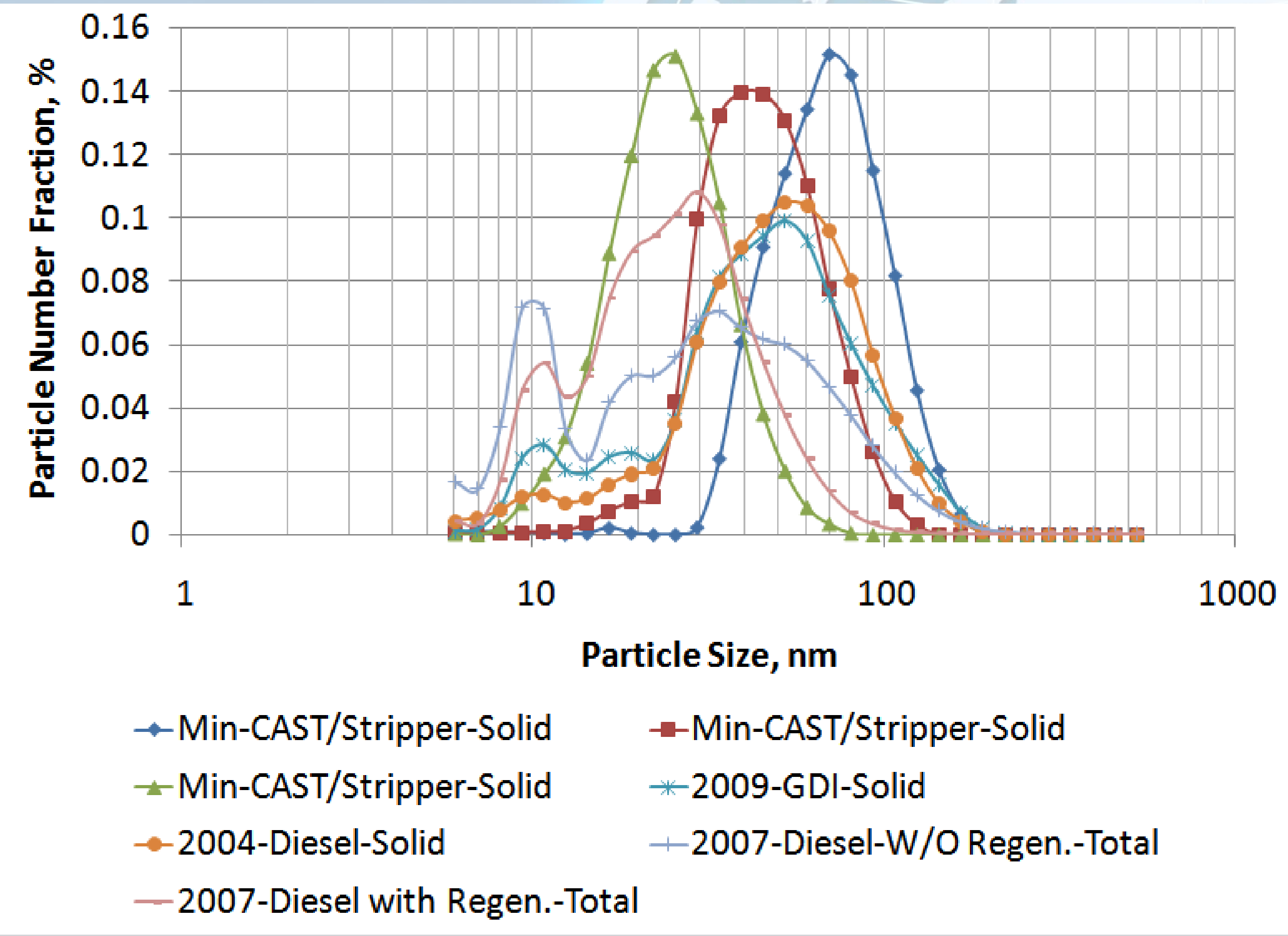
SO_3 or SO_4 and Sulfuric Acid Nucleation



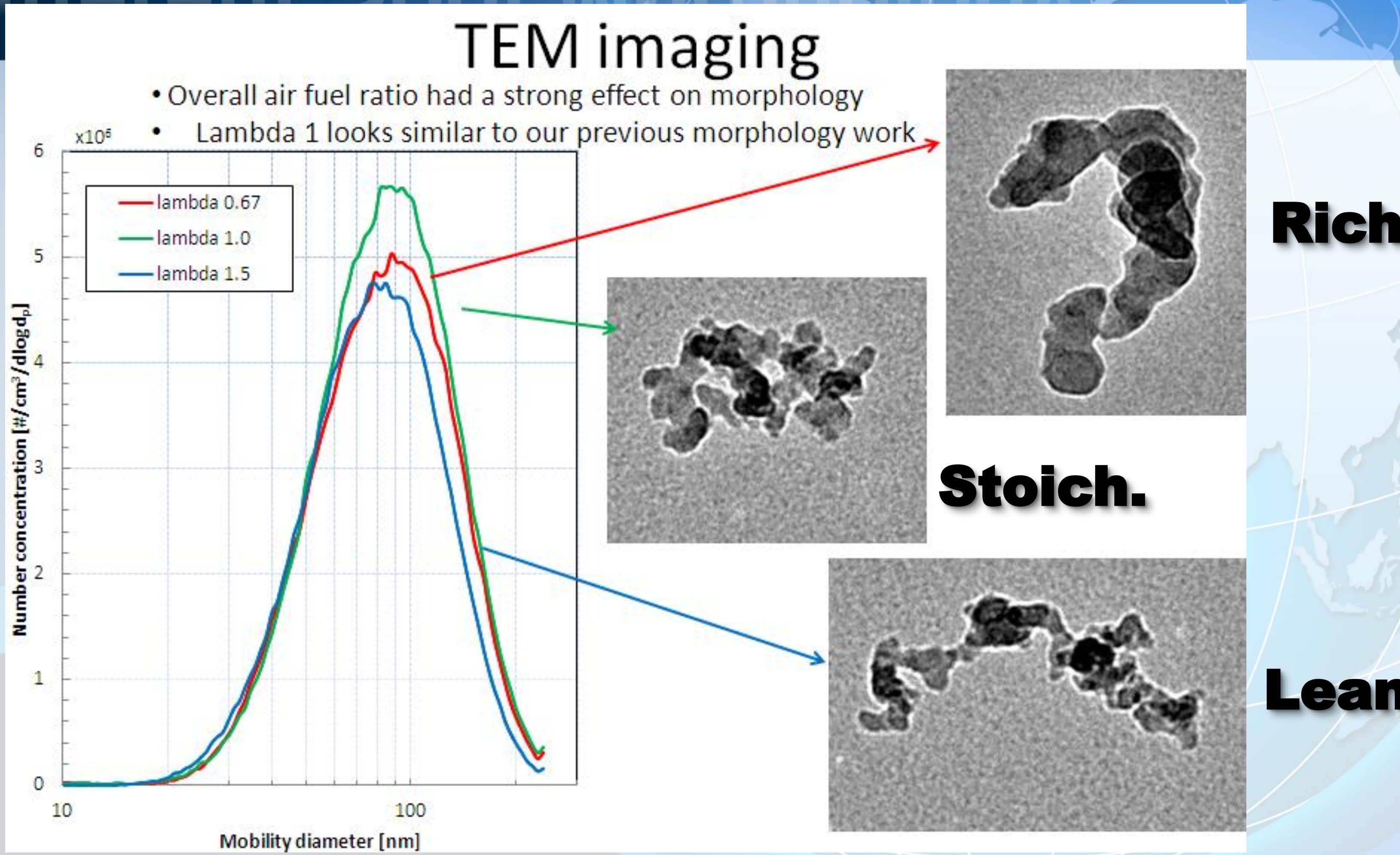


- SO3 or SO4 nucleation produced larger size distributions than that of sulfuric acid
- The increase in water significantly enhanced sulfuric acid nucleation and growth. Even at high concentration, the mode of the distribution on a number basis did not exceed 20 nm. This is what we typically see in engine exhaust nucleation and growth, but the growth is typically via hydrocarbons
- At very high water content (> 16% in exhaust, ~Natural Gas), large mode started to appear, especially on a mass basis.

Size Distributions for particle generator and different Engine Technology

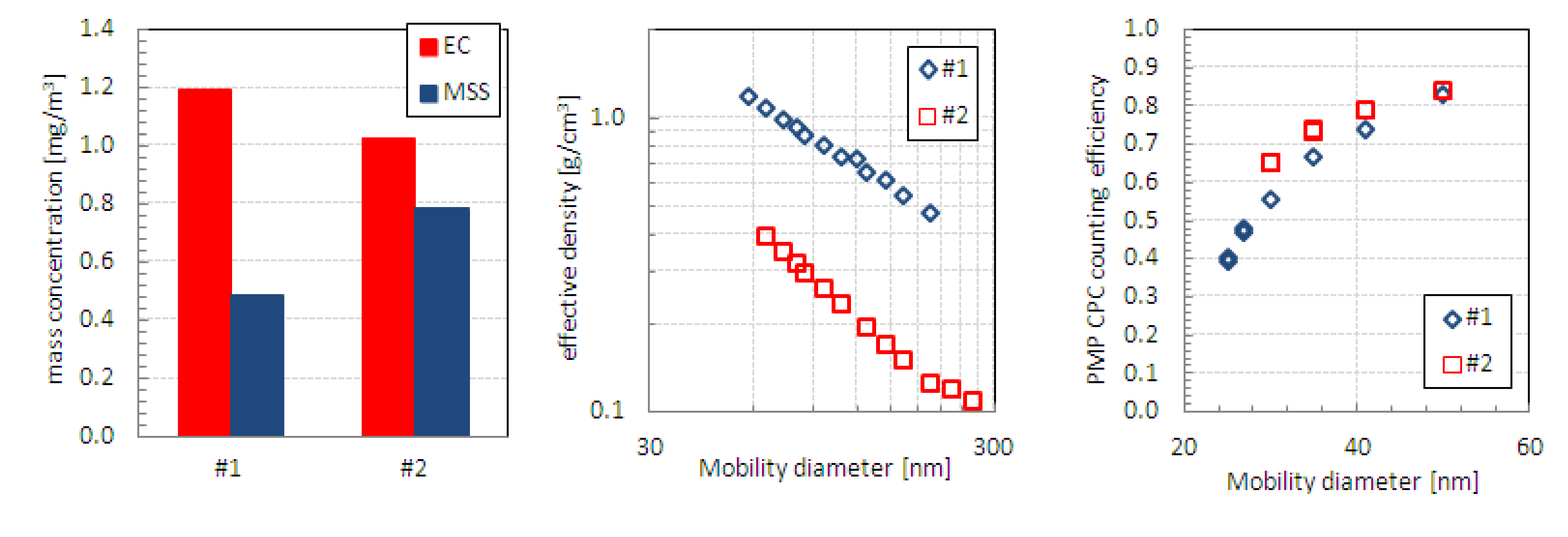


Different Soot Morphology



In-kind support of TEM images and analyses were provided by Argonne National Laboratory

MINICAST AEROSOL CHARACTERIZATION



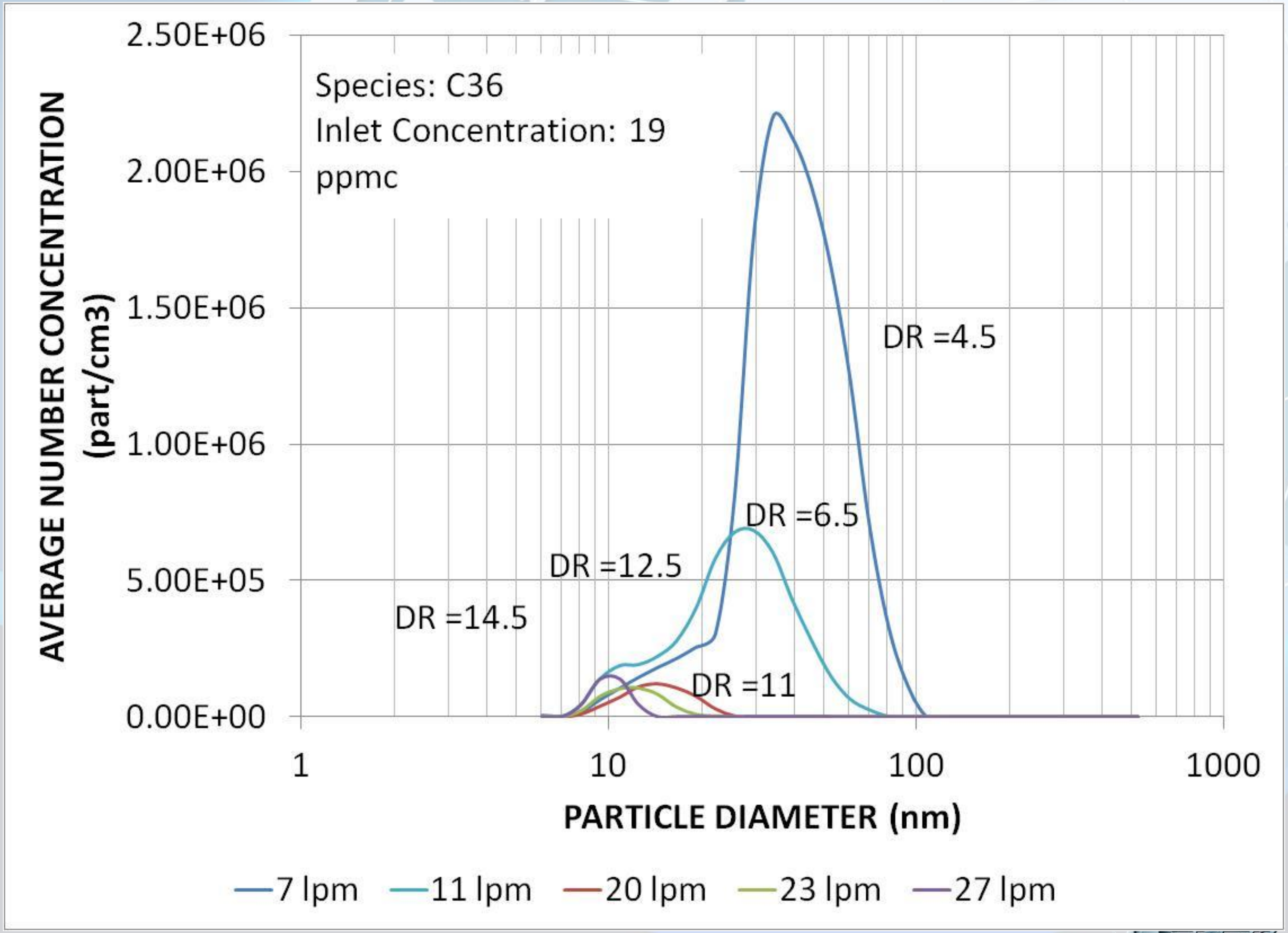
#1	#2
60 mlpm C_3H_8	60 mlpm C_3H_8
0 mlpm N_2	275 mlpm N_2
1 lpm air	1.85 lpm air
d_g at ~70 nm	d_g at ~80 nm

miniCAST operating conditions had a strong effect on the light absorption, effective density and particle affinity for butanol.

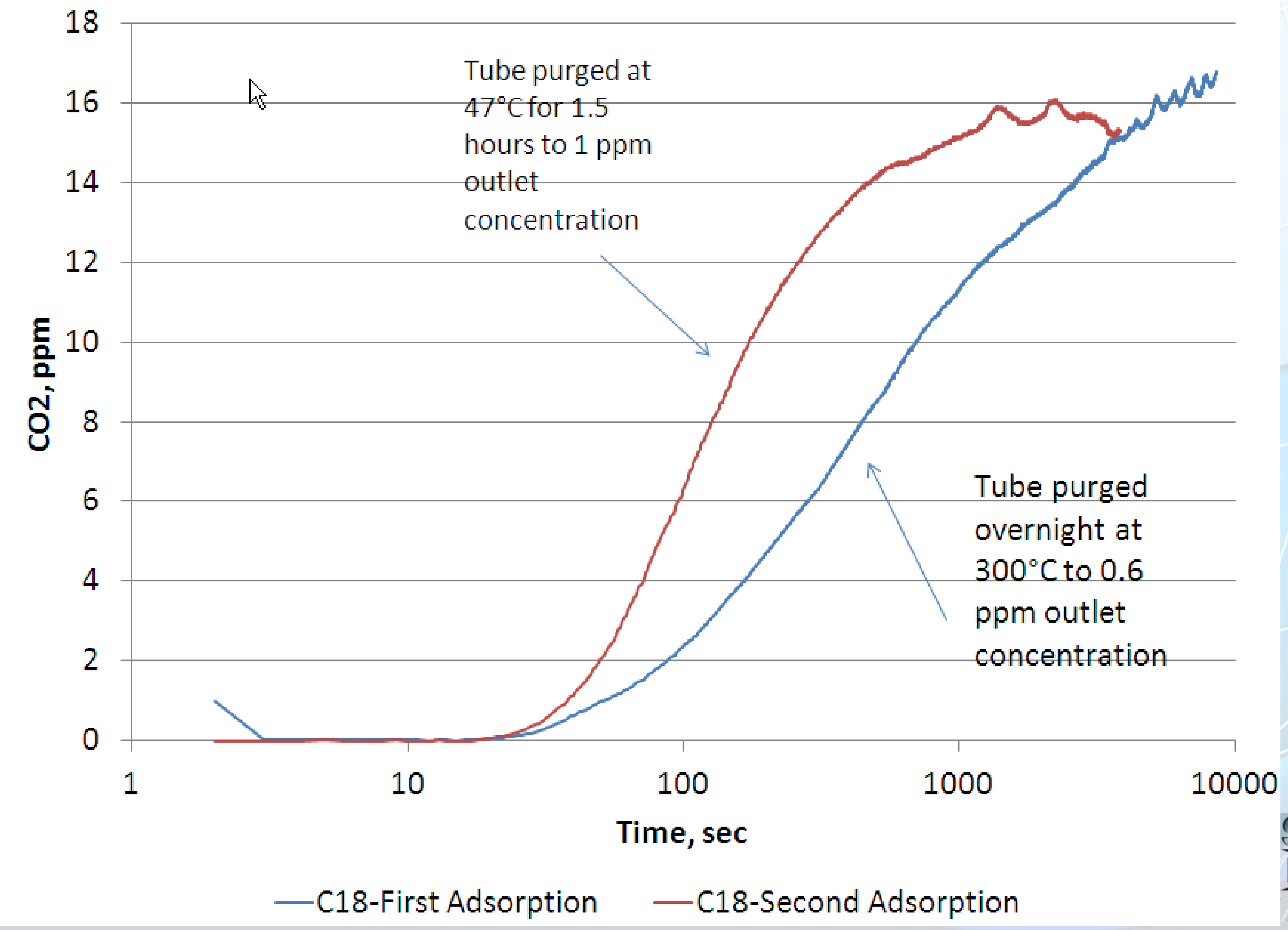
Characterization of Combustion Aerosol Produced by a Mini-CAST and Treated in a Catalytic Stripper
Mamakos, Khalek, Giannelli & Spears, AS&T, vol 47, issue 8, May 2013

Example of C36 Nucleation at Various Dilution Ratios

- It takes an extremely high saturation pressure ratio to nucleate and grow normal alkanes
- Significant part of the material is lost to the walls of the sampling system.
- The OC recovery after the lowest dilution was about ~8%



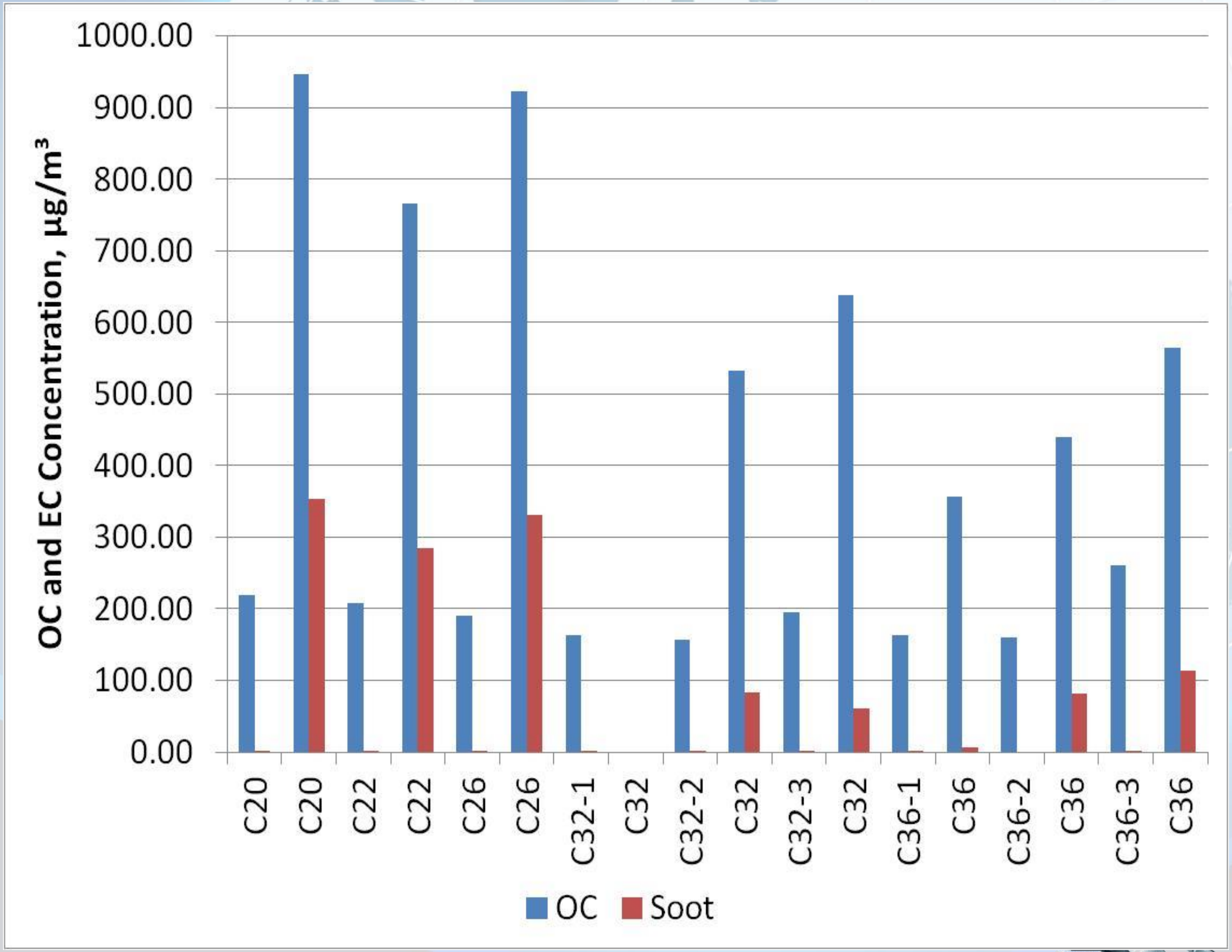
Adsorption in Sample Lines in sub-saturation regions



Hydrocarbon Transport in Sampling System in the Presence and Absence of Soot

- Significant HC loss was observed in the absence of soot. Soot acts as a transport mechanism of species

- Implication:
  - **This poses a challenge for the accurate measurement of toxic compounds emitted from modern engines with DPF in the absence of soot**



Summary

- **The development of the particle generator is work in progress. It has been very helpful in studying and understanding several processes in aerosol research that may enhance and improve our understanding of PM sampling and gas phase particle precursor effects.**

Acknowledgements

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