A New Catalytic Stripper for Removal of Volatile Particles

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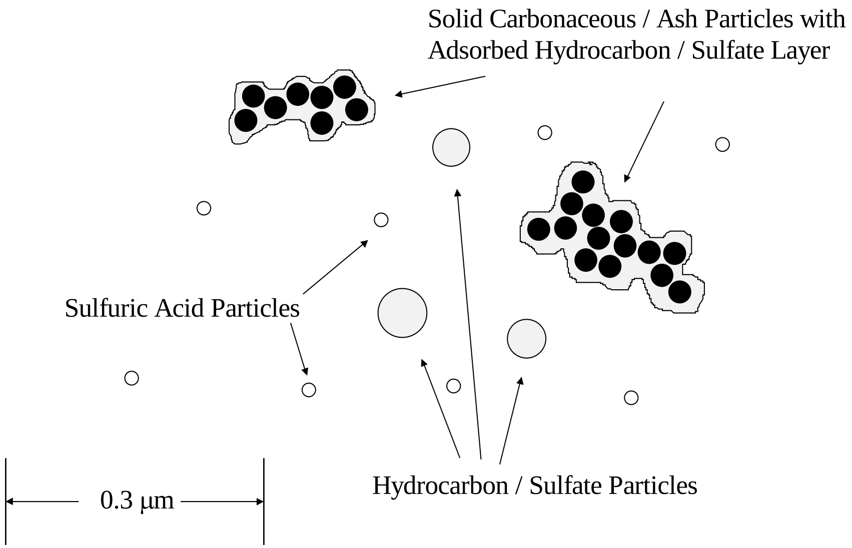
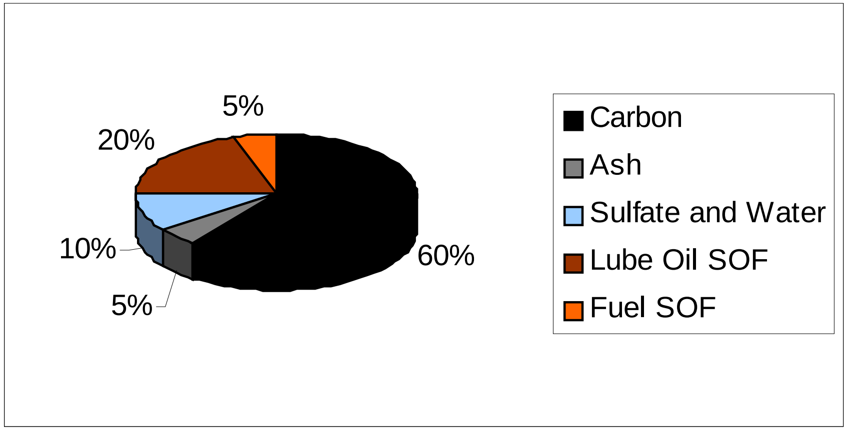
7th ETH Conference on Combustion Generated Particles
Zurich, 18th - 20th August 2003

We gratefully acknowledge the support of Johnson-Matthey in developing and providing the catalyst section

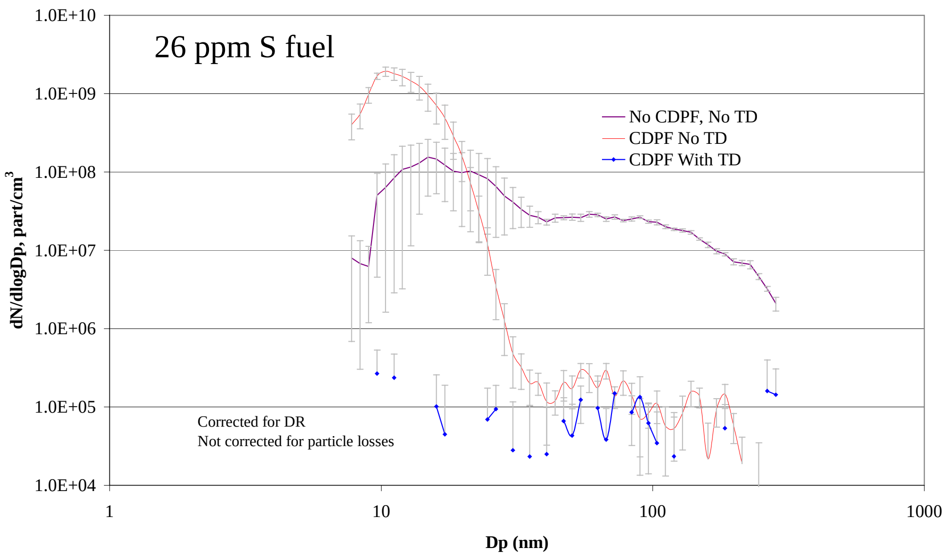
Typical Composition and Structure of Diesel Particulate Matter

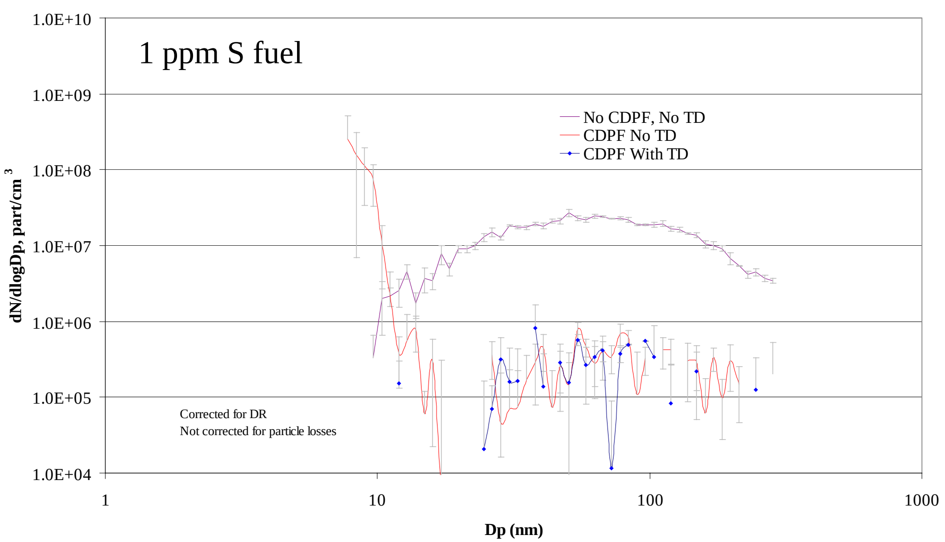
- Solid particles are typically carbonaceous chain agglomerates and ash and usually comprise most of the particle mass
- Volatile or semi-volatile matter (sulfur compounds and organics (SOF)) typically constitutes 30% (5-90%) of the particle mass, 90% (30-99%) of the particle number
- Carbon and sulfur compounds derive mainly from fuel
- SOF and ash derive mainly from oil
- Most of the volatile and semi-volatile materials undergo gas-to-particle conversion as exhaust cools and dilutes
- The smallest particles (nuclei mode) are usually volatile but may be solid in some cases
- **We need to distinguish between solid and volatile particles across the size range**





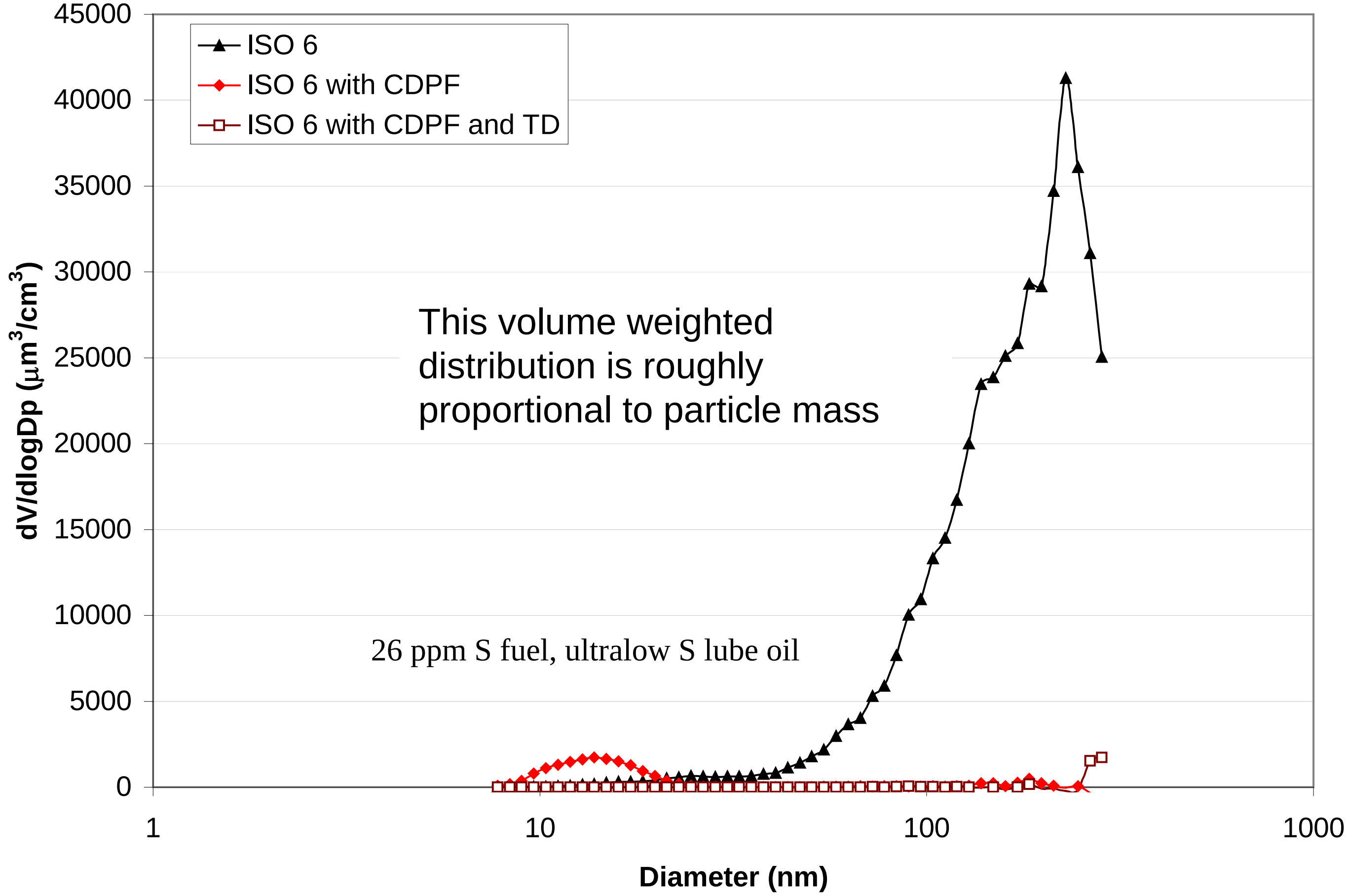
Formation of a volatile nuclei mode downstream of a catalyzed Diesel particulate filter (DPF)



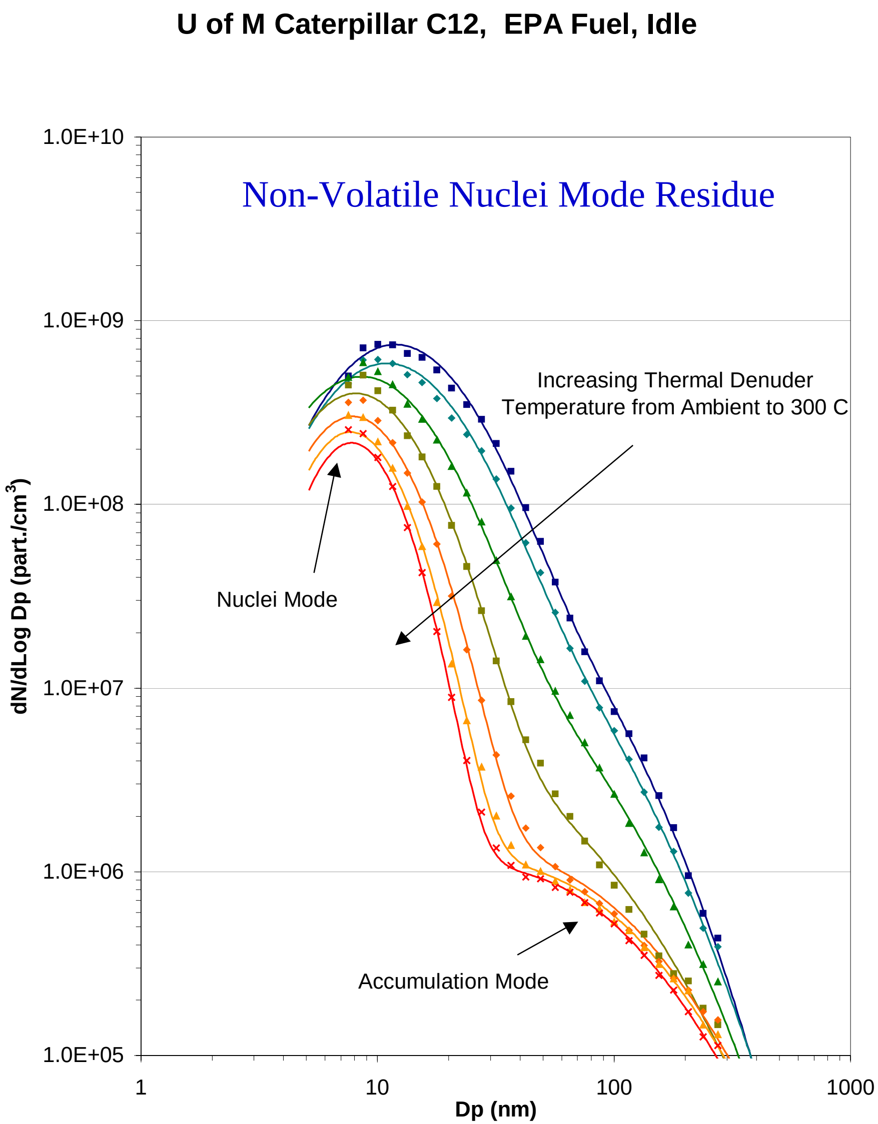


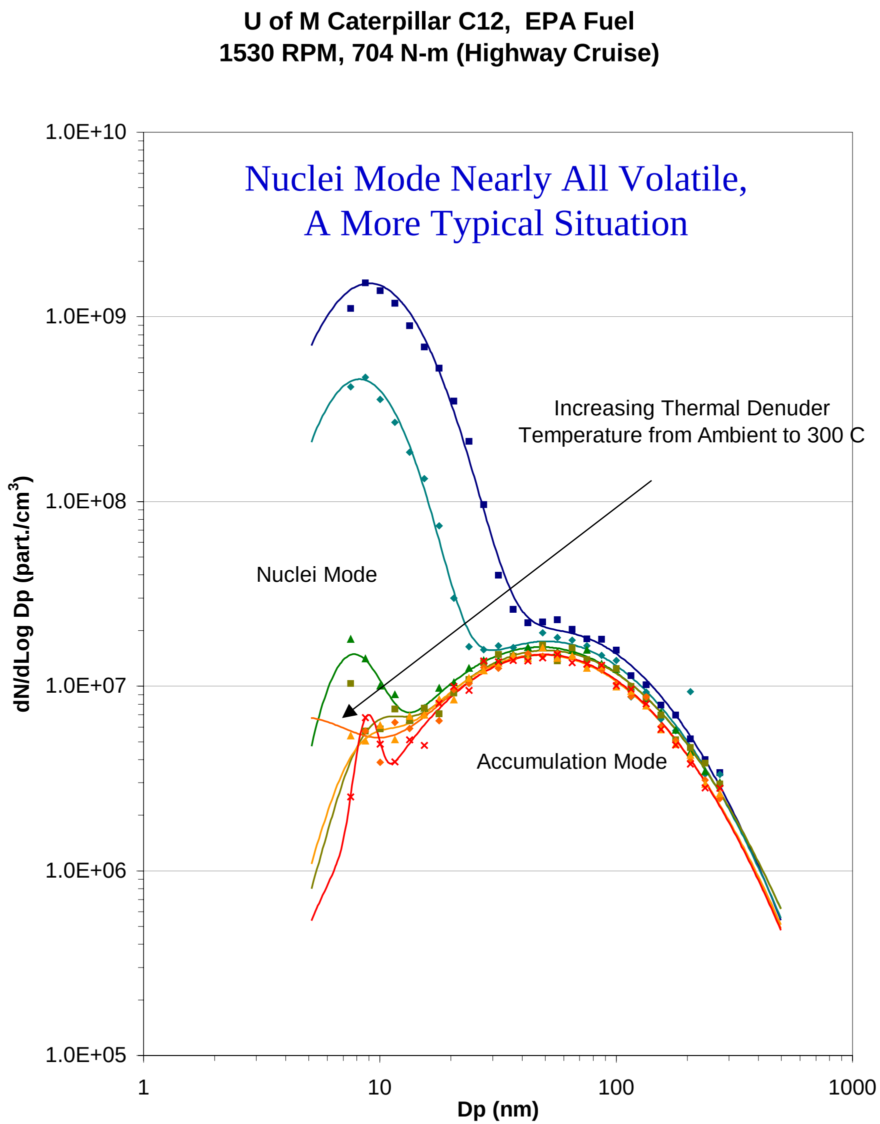
- The results shown are for tests of a catalyzed DPF on a modern Cummins engine
- DPF very efficient for solid particles
- May form a very large nuclei mode downstream of DPF at high load conditions
- Size of mode increases with sulfur content of fuel, but still observed with near zero sulfur fuel
- Sulfuric acid likely major component

A volatile nuclei mode is all that survives downstream of a catalyzed (DPF)



Thermal Denuder Measurements Show the Nuclei Mode is Usually Volatile but Reveal Nonvolatile Core at Light Load



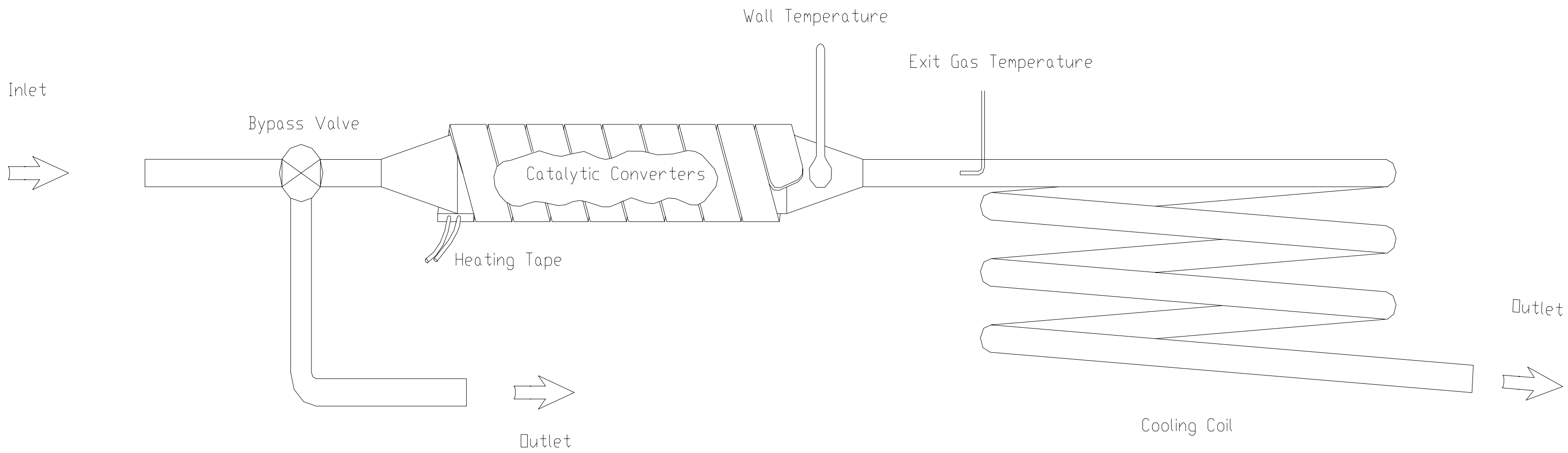


Means of identifying volatile and solid particles in near real time

- Some particle mass spectrometers
- Hot primary dilution
- Thermal denuder – a heating section followed by an activated charcoal bed
  - Needs to be characterized for losses
  - Recondensation of volatiles on accumulation mode a problem
  - Charcoal must be replaced frequently
- Catalytic stripper – catalytic oxidation of hydrocarbons, trapping of sulfates, followed by a cooling or dilution section
  - Original design[1] did not have sulfur trap and was not characterized for nanoparticle loss
  - Needs to be characterized for losses
  - Sulfur trap maintenance (yearly of more?)

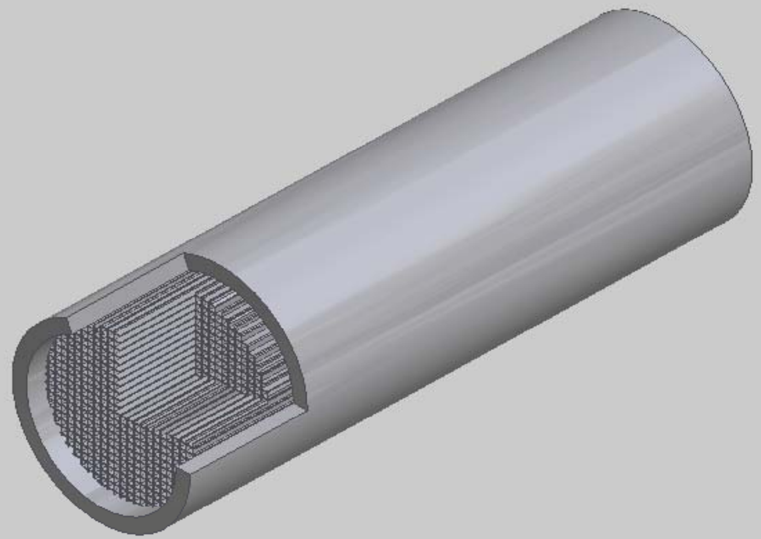
1- Abdul-Khalek, I.S. and D.B. Kittelson. 1995. "Real Time Measurement of Volatile and Solid Exhaust Particles Using a Mini-Catalyst," SAE Paper No. 950236

Stripper layout



- The stripper consists of a 2 substrate catalyst followed by a cooling cool
- The first substrate removes sulfur compounds
- The second substrate is an oxidizing catalyst
- The catalysts were provided by Johnson-Matthey

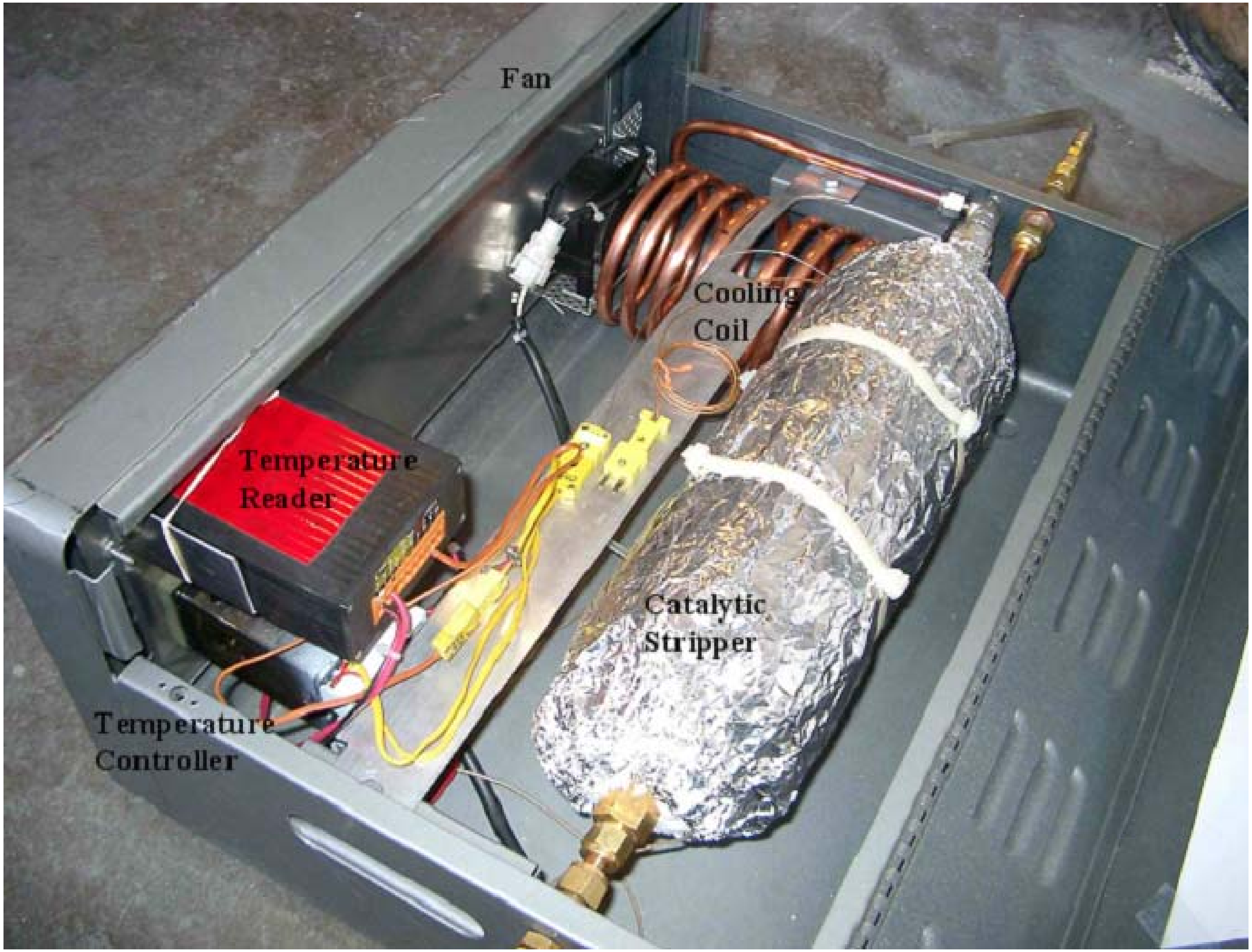
Properties of the catalysts



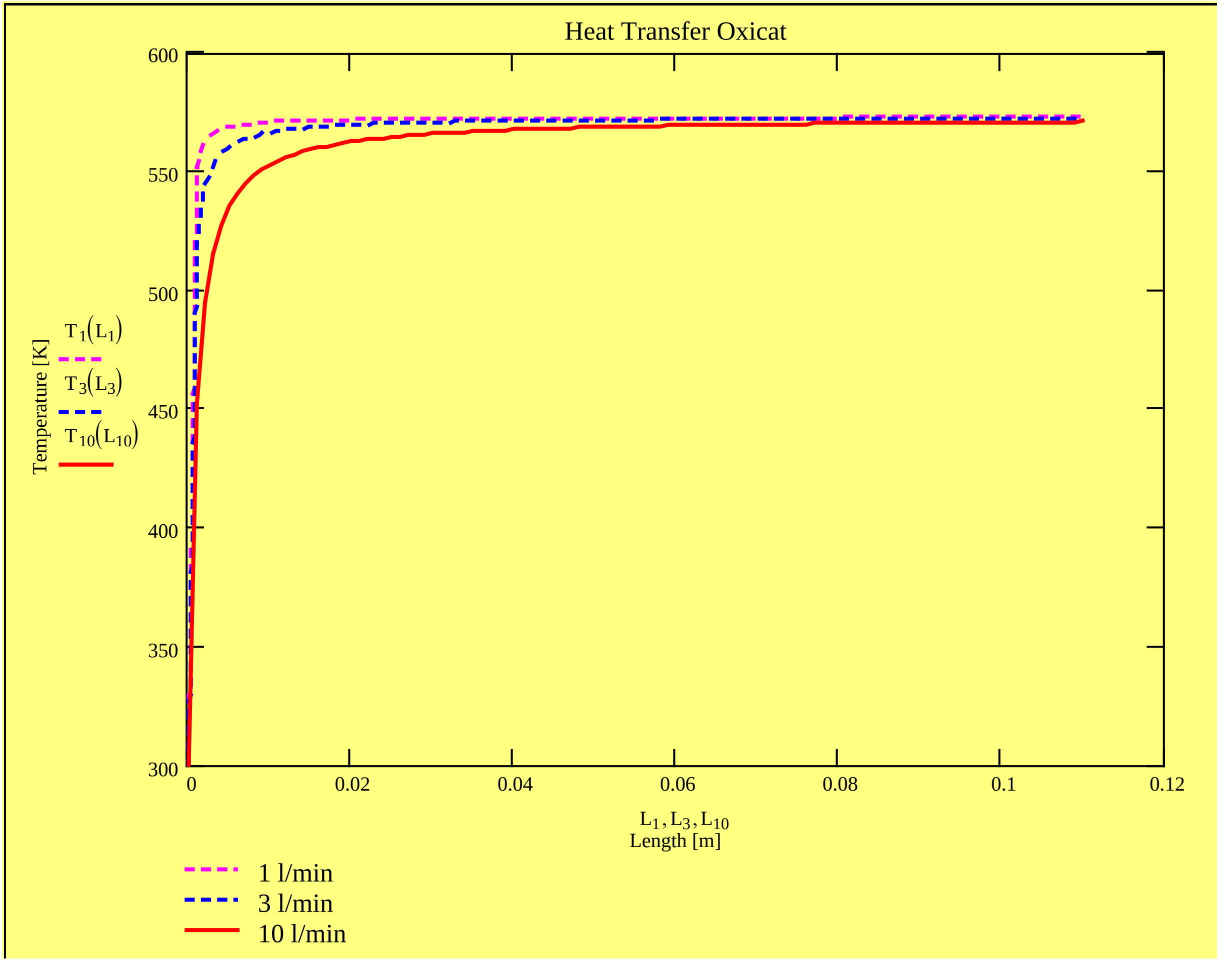
Catalyst Properties

	Oxicat:	S-Trap:
Length:	110 mm	110 mm
Diameter:	32 mm	32 mm
Channel Dimensions:	1,116 x 1,116 x 110 mm	1,037 x 1,037 x 110 mm
Channel Density:	350 cpsi	400 cpsi
Wall Thickness:	5,5 mil	6,0 mil
Washcoat Loading:	1,223 g/cm^3	1,267 g/cm^3
Washcoat Density:	1,500 g/cm^3	1,630 g/cm^3

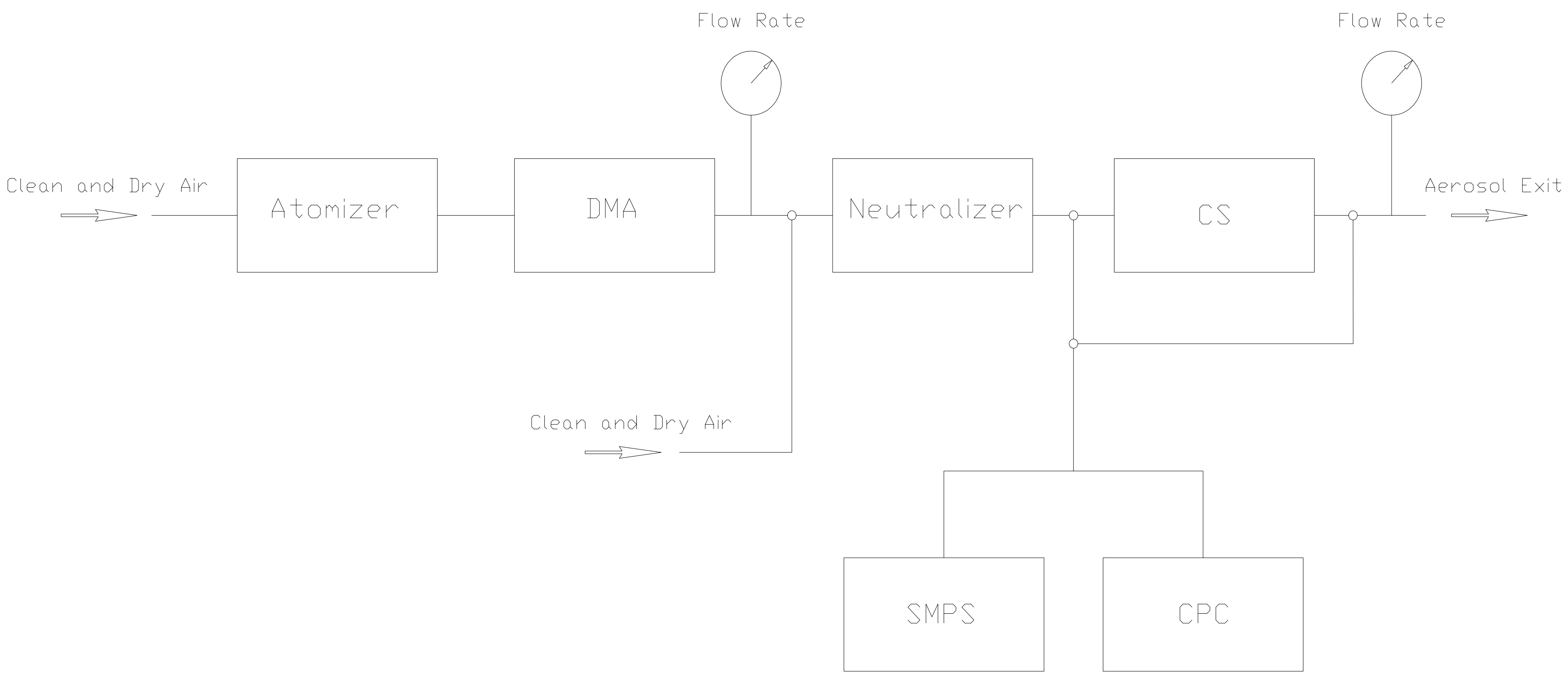
Physical layout of the stripper



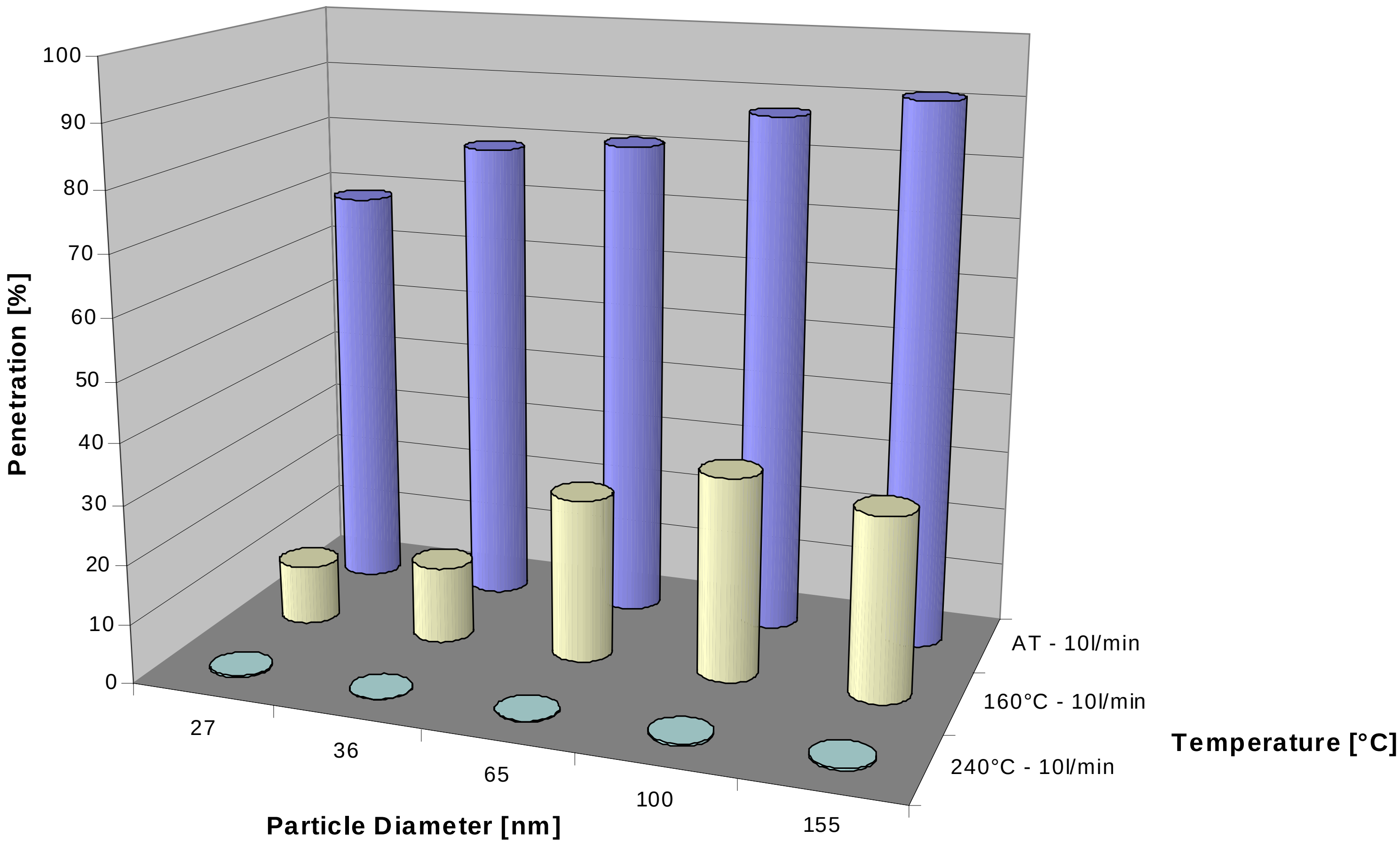
Heat and mass transfer performance



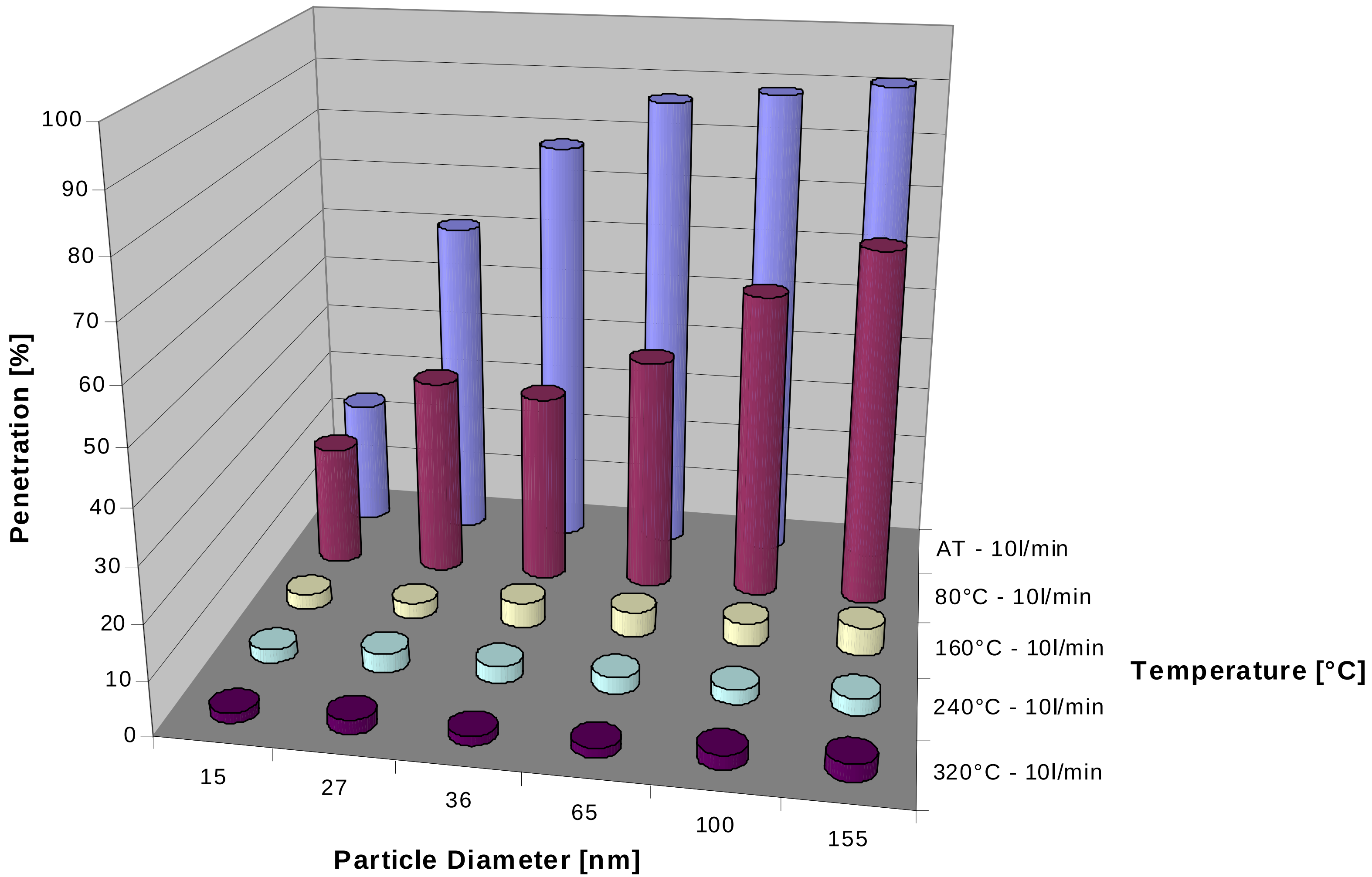
Stripper performance tests: experimental setup



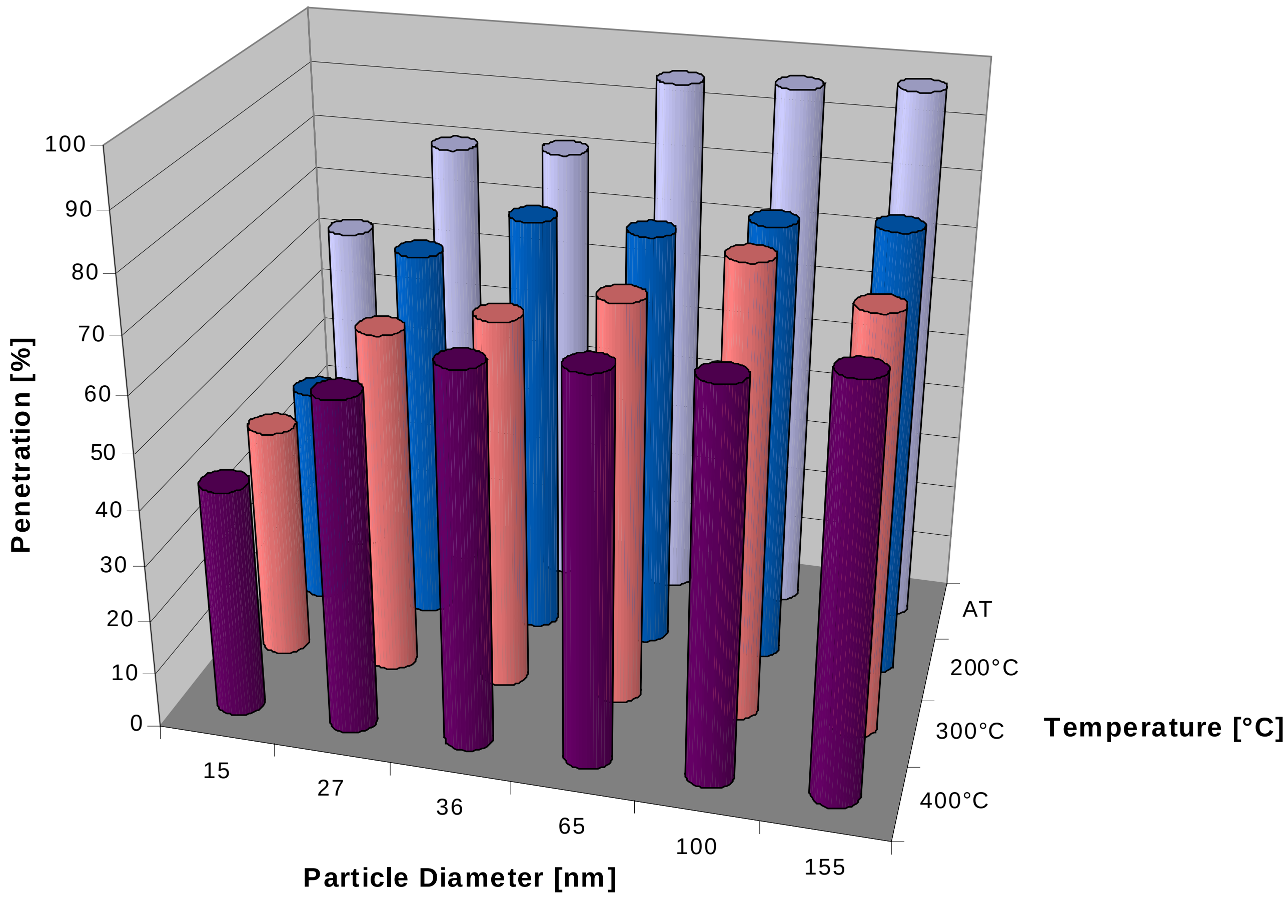
Sulfate particle ($(NH_4)_2SO_4$) removal, 10 lpm



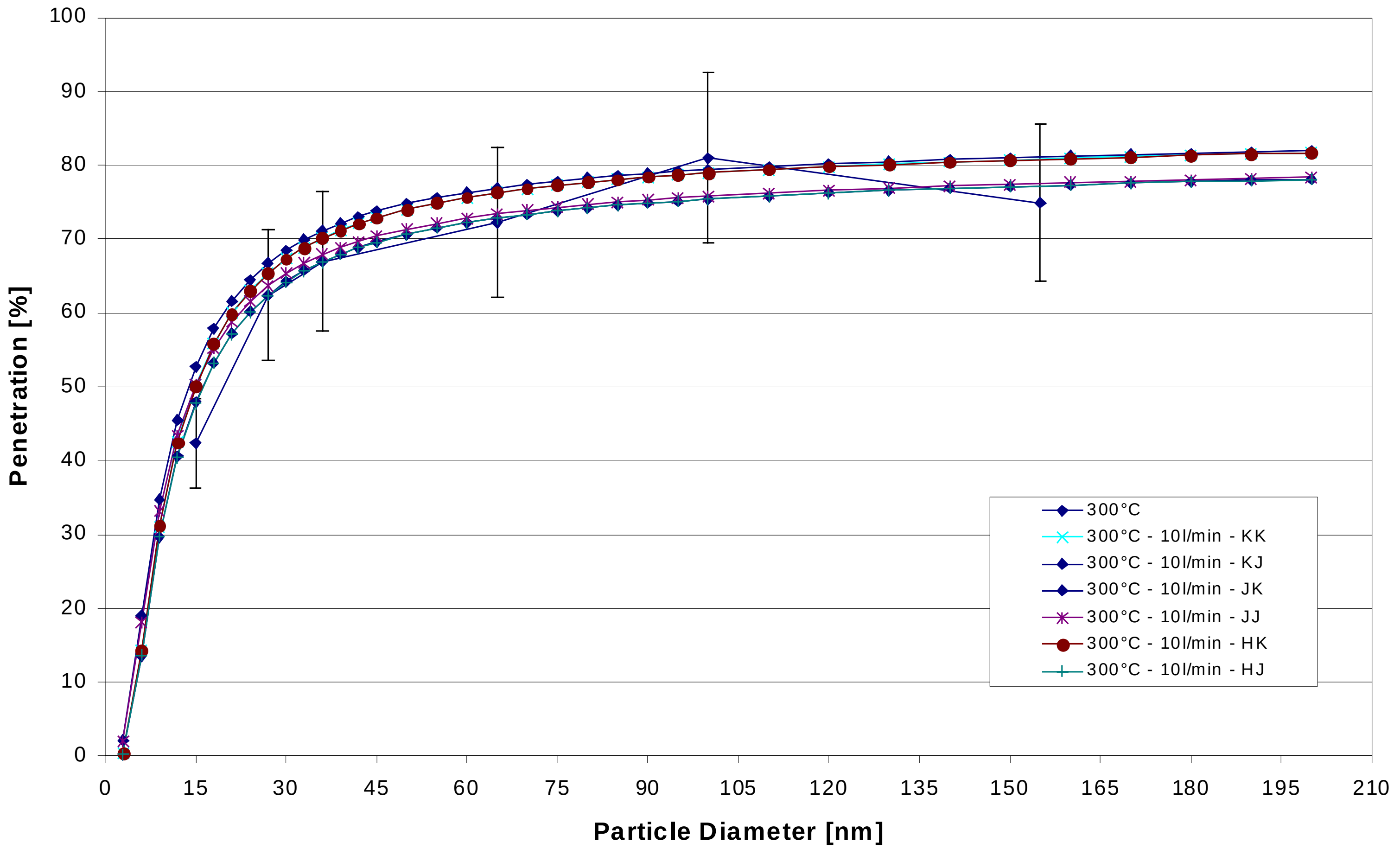
Engine oil particle removal, 10 lpm



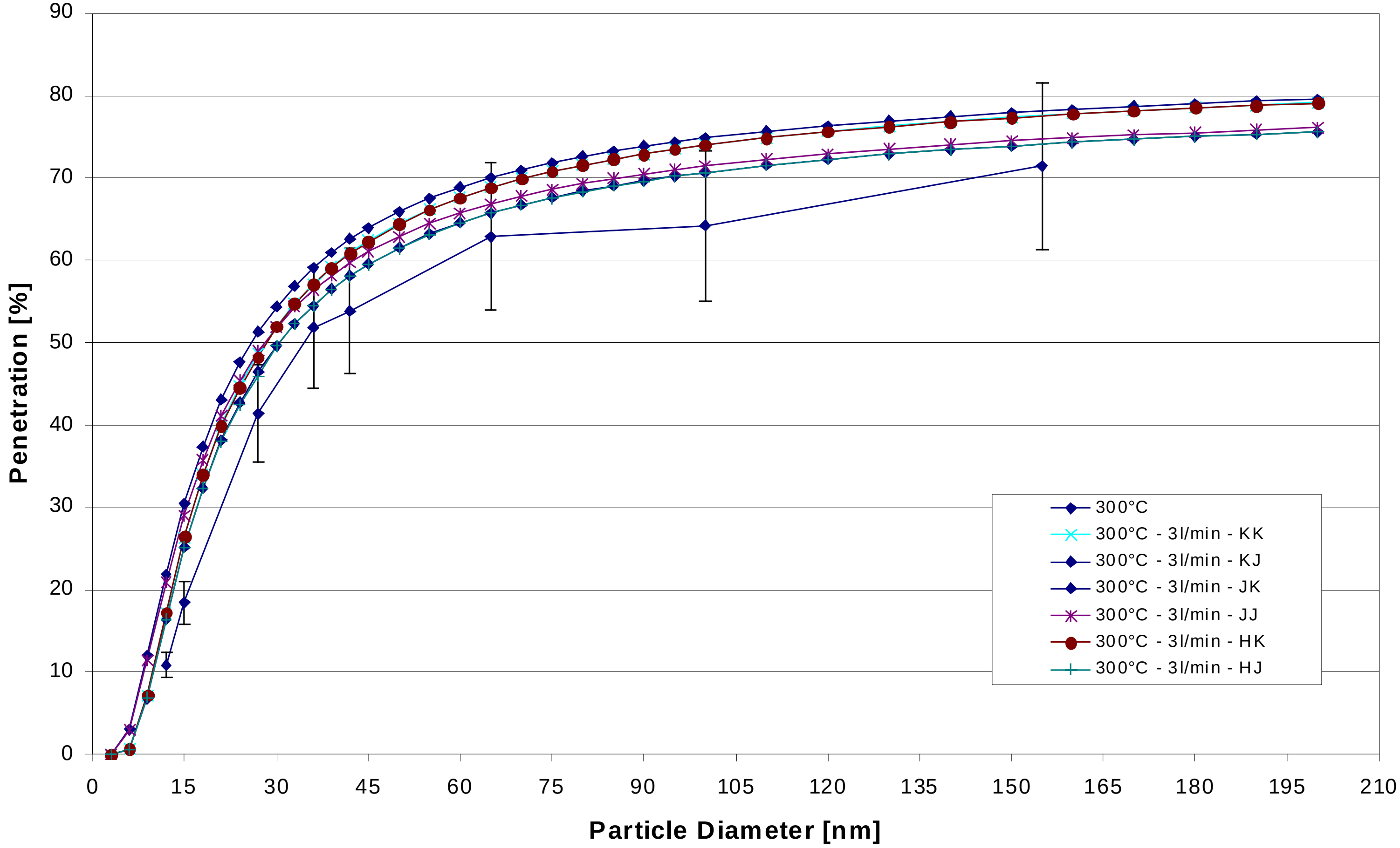
Solid particle penetration (NaCl) at 10 lpm



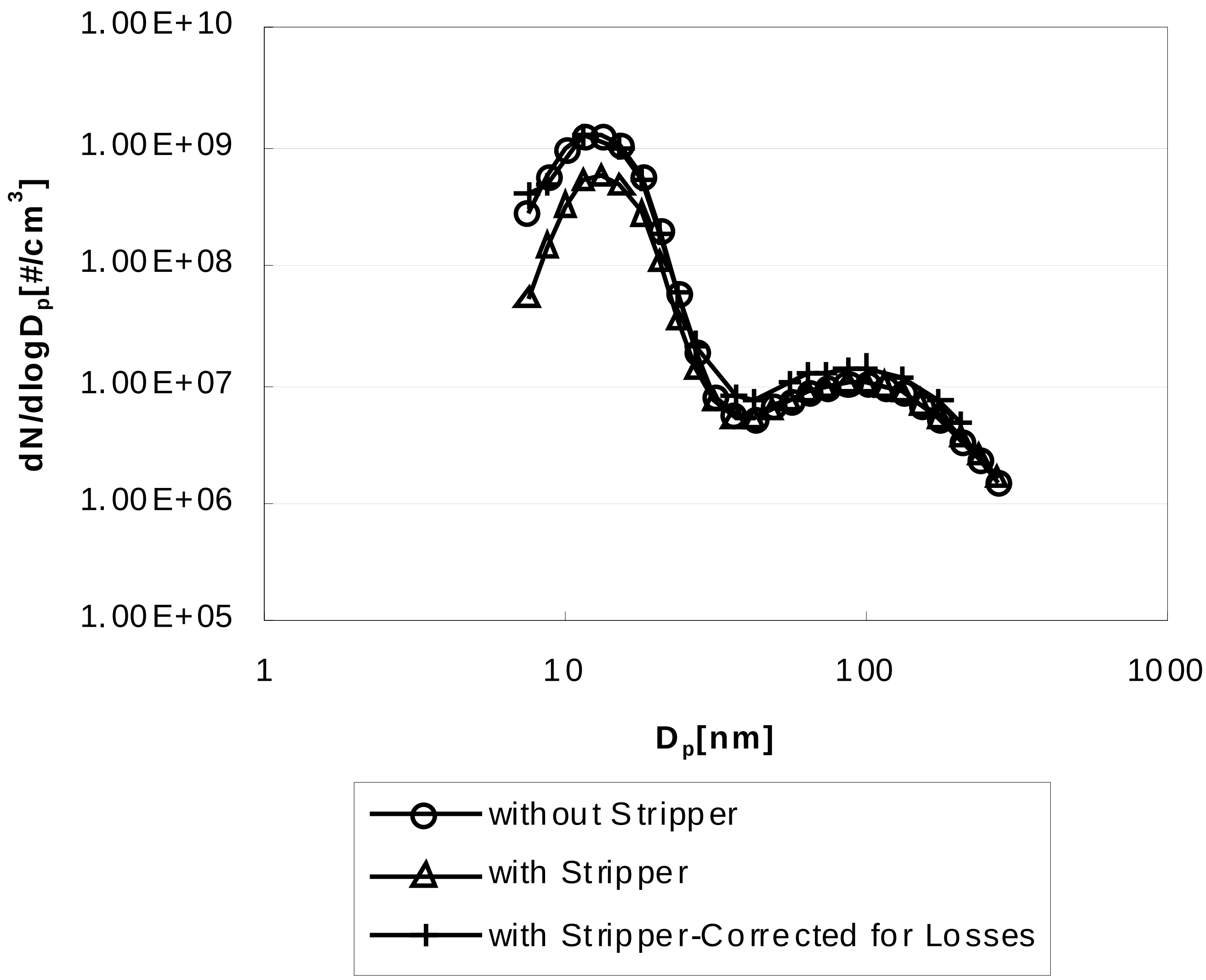
Solid particle penetration at 10 lpm, 300 C



Solid particle penetration at 3 lpm, 300 C



Performance with a solid nuclei mode formed from lube oil metal compounds (Ca, Zn)



Conclusions

- Near 100% removal of volatile particles across size range of interest demonstrated
- With loss correction, correct measurement of of solid particles across size range of interest demonstrated
- Diffusion and thermophoretic losses of solid particles fully characterized
  - Thermophoretic losses are particle size and flowrate independent, predictable and modest (~20% at design temperature)
  - Diffusion losses mainly effect nuclei mode particles
    - » Losses are strongly size and flowrate dependent
    - » Losses of 10 nm particles about 60% at 10 lpm, 90% at 3 lpm
    - » Losses are predictable and further optimization possible