Cold Start DI Gasoline Particulate Emissions

Philip Price, Prof. Richard Stone
University of Oxford

Dave OudeNijeweme, Dr Xiangdong Chen
Jaguar Powertrain

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Jaguar Cars

Kerstin Jurkschat

Department of Materials Science, University of Oxford

Engineering and Physical Sciences Research Council

Summary

1. Background: DI Gasoline Engines, their PM Emissions and Cold Start Effects

2. Experimental Details: Hardware, Sampling system and Measurement of PM Emissions

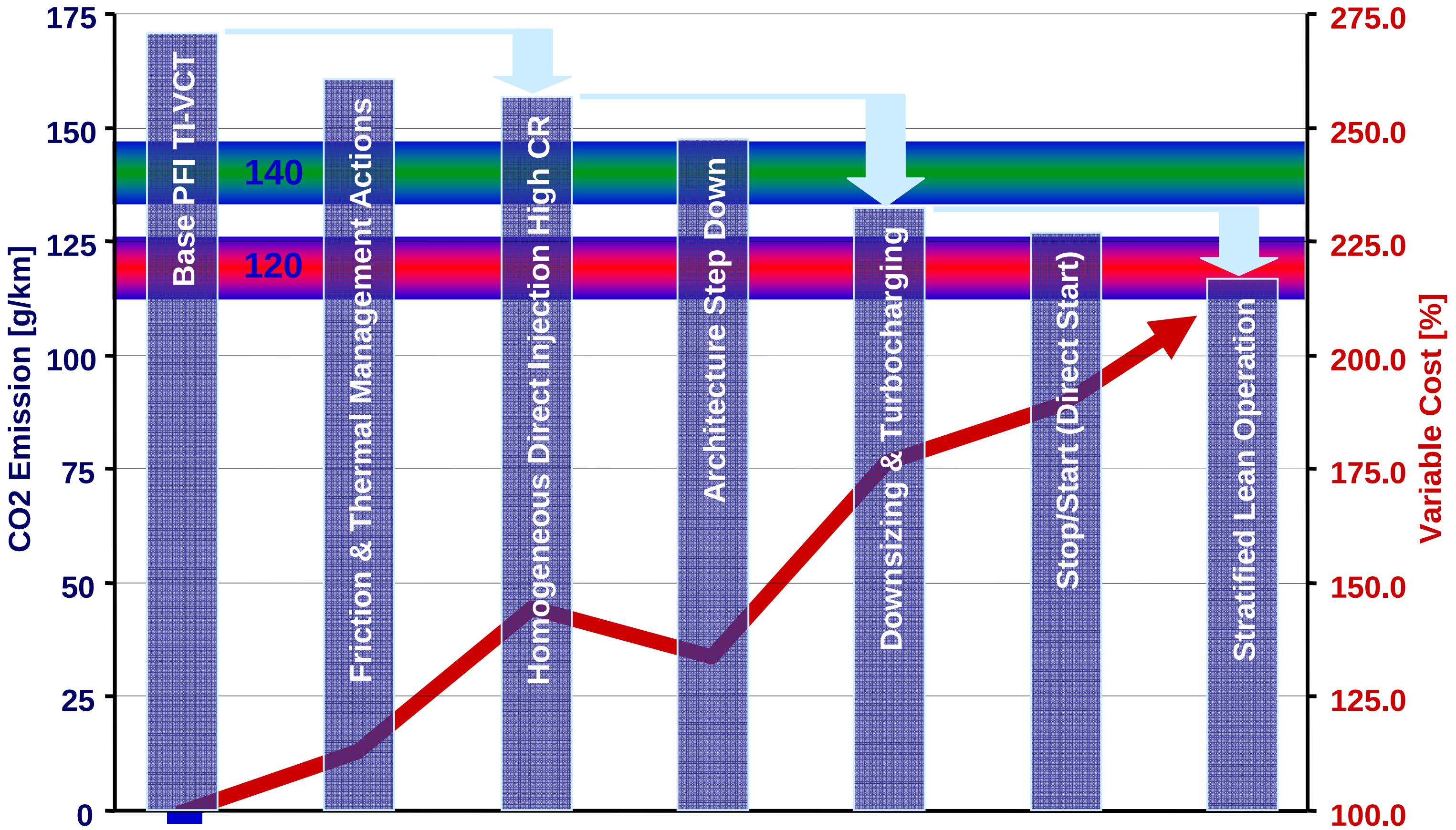
2. HC Emissions and their Temperature Dependence

3. PM Size Distributions and Composition (Thermo-gravimetric Analysis)

4. Volatile PM Analysis (Thermo-gravimetry)

5. PM Geometrical Size and Morphology (HR – TEM & DMS500)

CO_2-Reduction Strategy Example



- ACEA commitment requires CO_2 reduction
- c40% CO_2 reduction possible through combination of above technologies

Figure from Martin Wirth: 27. International Vienna Engine Symposium 2006

Background – Comparison of DI to Port Fuel Injection

- Lower throttling loss: Stratified charge mode, higher EGR tolerance, (downsizing)

- Higher specific power output: enables downsizing

- Faster catalyst light-off: split injection → large exhaust heat fluxes

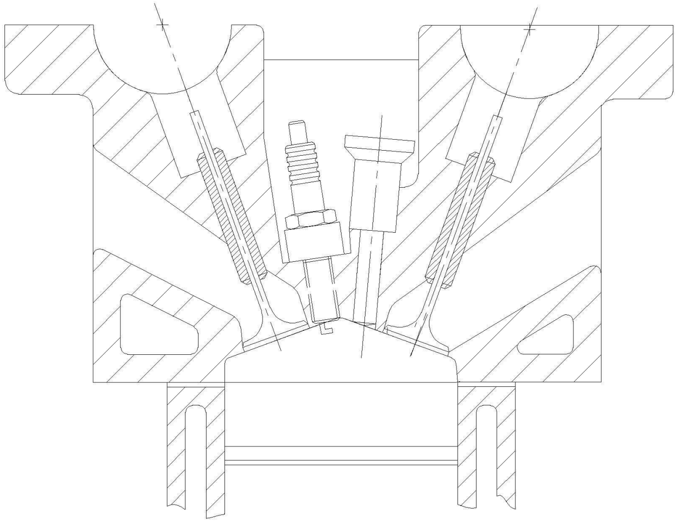
- Improved fuel metering control, better droplet atomization, improved transient response

- Synergies with downsizing and forced induction:

    - Higher specific power output due to charge cooling effect on volumetric efficiency

    - higher CR improves low end torque in forced induction applications

Background – DI Gasoline PM Emissions



Second Generation DI Combustion System

Closely spaced centrally mounted injector and spark plug. Flat top piston.

Factors that influence PM Emissions:

- Reduced time available for mixture preparation

- Piston and liner wetting

→ Local oxygen privation either close to surfaces or around incompletely vaporised fuel droplets → formation of elemental carbon particles

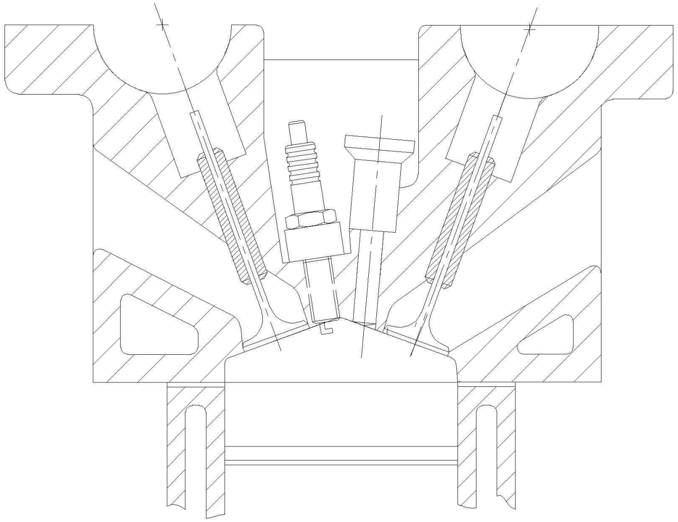
- Since the above are local effects only, soot emission rates are normally lower than from compression ignition engines

- At low loads: High saturation ratios for condensable species and comparatively low total soot surface means that the condensed organic fraction can be a significant contribution to the emitted PM

Background – Mixture Preparation and Cold Starts

In SI engines, PM emissions have a strong dependence on mixture preparation:

- incomplete evaporation
- presence of fuel droplets
- fuel films on surfaces
- AFR Stratification



Worsened by:

- Downsizing (higher internal loads)
- Forced induction (more fuel to evaporate)
- Biofuel blends (higher Δh_{fg} and lower calorific values)
- **Cold starts** (Habchi et. al: up to 25% of the injected fuel mass on surfaces)

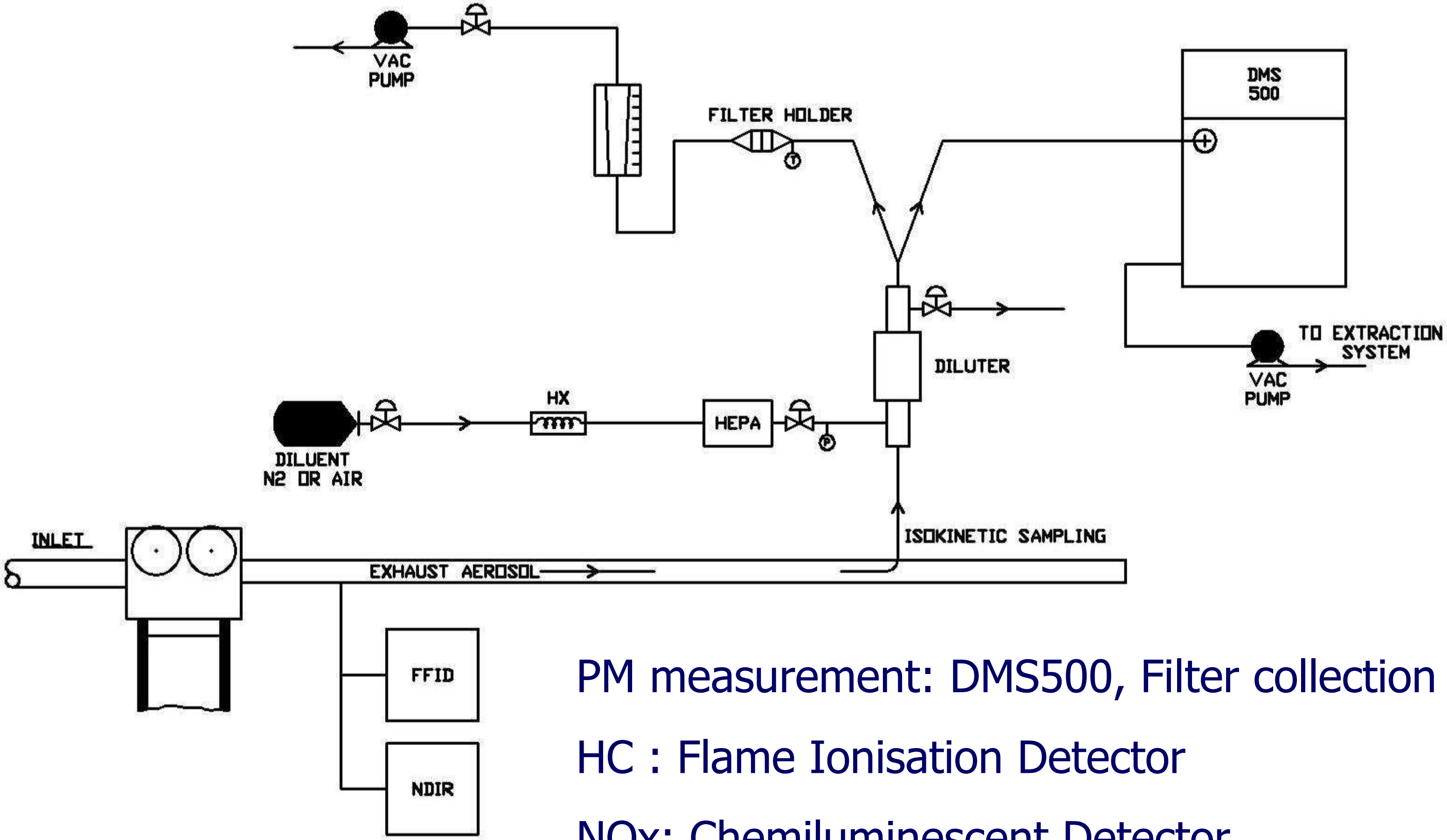
Habchi *et. al.* Influence of the Wall Temperature on the Mixture Preparation in DI Gasoline Engines. Oil and Gas Science and Technology – Rev. IFP, Vol 54 (1999), No.2 pp211 – 222.

Test Matrix and Engine Specification

Engine type	4 Stroke
Combustion system	Spray Guided Direct Injection
Bore x stroke	89 x 90 mm
Swept volume	562 cm^3
Compression ratio	9.5:1
Injector type	Solenoid Multi-hole Nozzle (150 bar)
Engine speed	1750 rpm
Inlet manifold pressure	1.0 bar
Nominal indicated mean effective pressure	9.0 bar
Fuel	Unleaded Gasoline

Test	AFR	Fuel Pressure (bar)	Start of Injection (CAD bTDC)
A	12	50	300
B	12	50	240
C	12	150	300
D	12	150	240
E*	14	100	270
F	16	50	300
G	16	50	240
H	16	150	300
I	16	150	240

Experiment



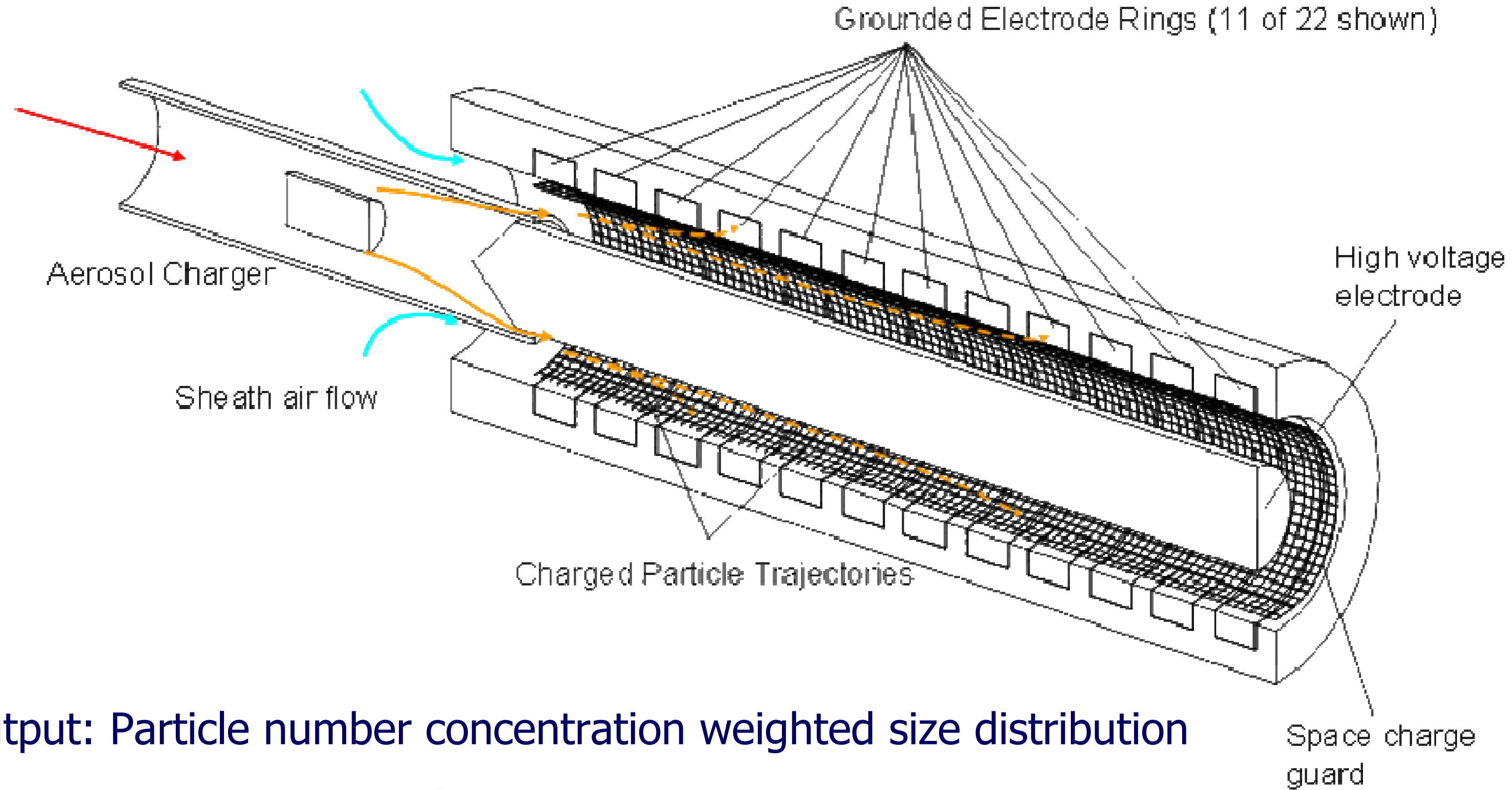
PM measurement: DMS500, Filter collection for TGA

HC : Flame Ionisation Detector

NOx: Chemiluminescent Detector

CO and CO2: Non Dispersive IR

Electrical Mobility Classification



Output: Particle number concentration weighted size distribution

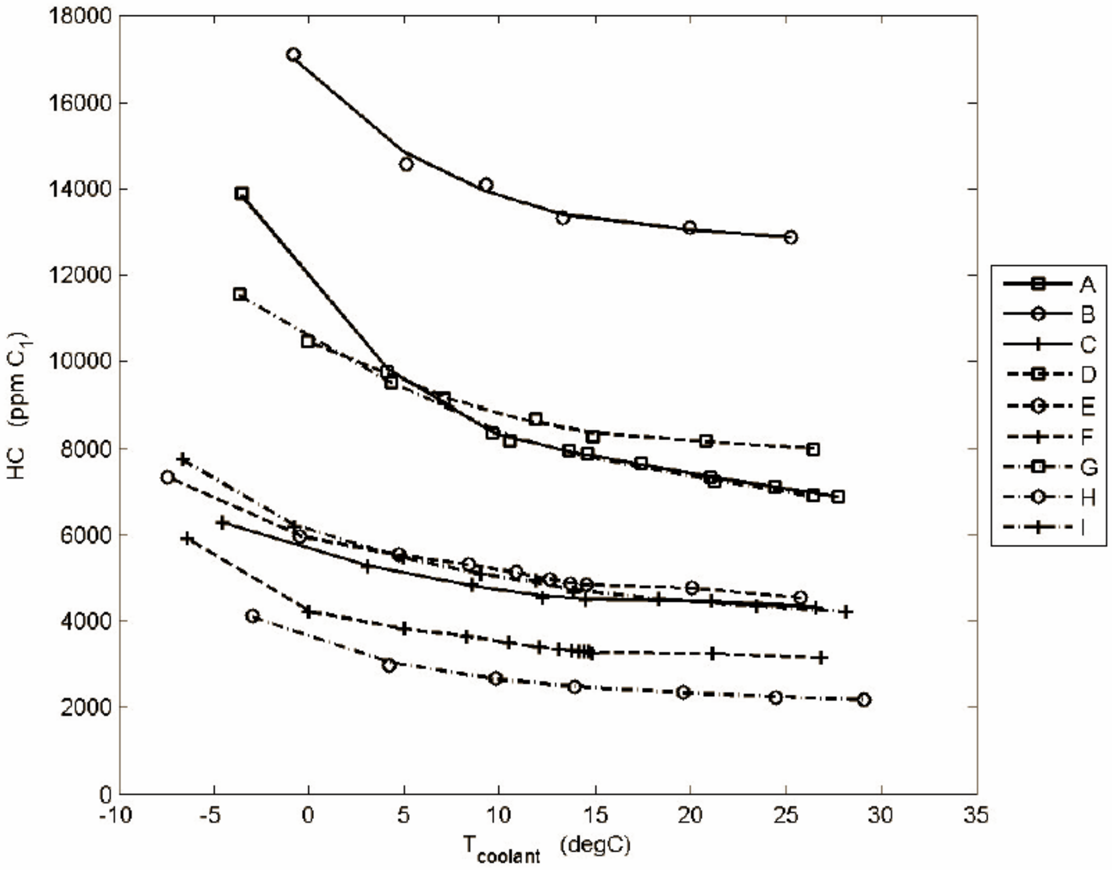
Particle size range: $5 < d_p < 1000$ nm

Time response: 0.2 s

Reavell *et. al.* SAE 2002-01-2714,

Symonds *et. al.* Aerosol Science **38** (2007) pp 52-68.

Results: Feed-gas HC Emissions vs Temp



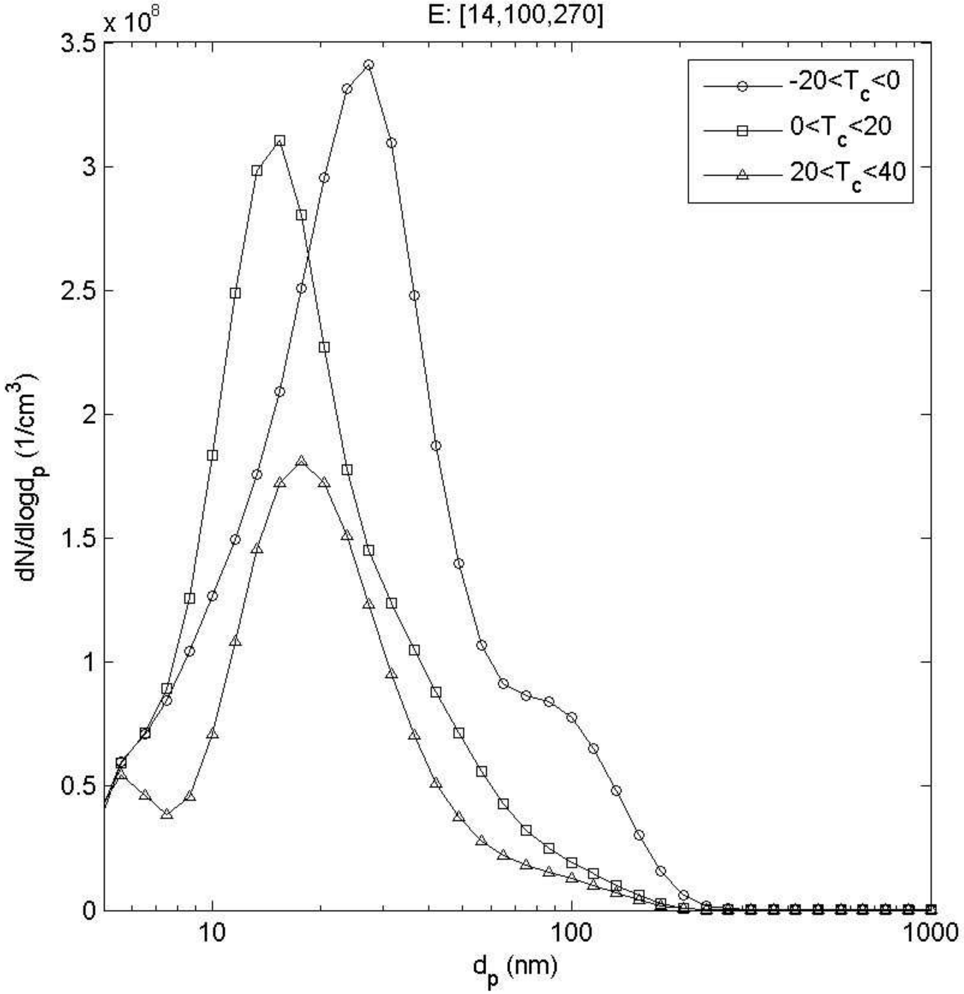
[HC] higher at cold temperatures because:

- increased flame quenching at low T because the thermal boundary layer is thicker.
- Increased absorption of fuel to the lube oil layer on liner surface.
- Larger crevice volumes

PM Dependence on Coolant Temperature

Thermo-gravimetric Analysis	
	PM Mass Fraction (%)
Light Organic	44.3
Heavy Organic	42.9
EC	12.8

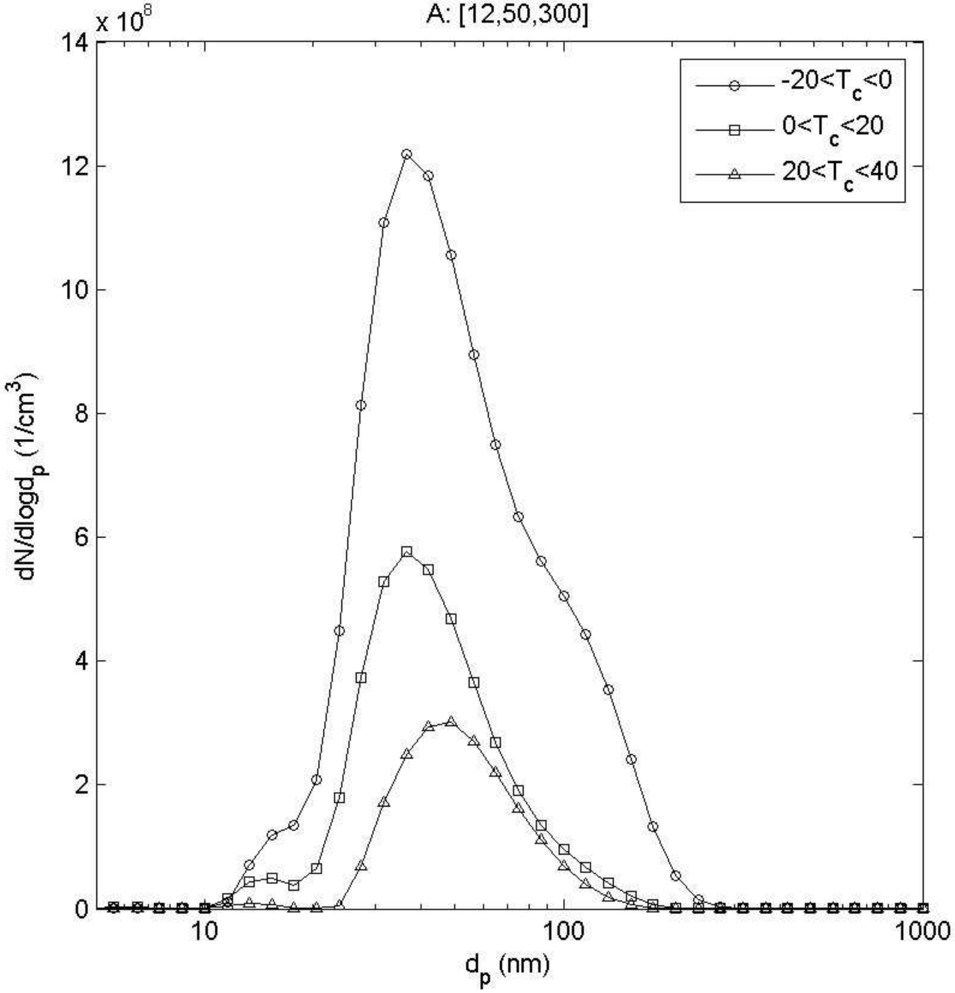
$N_{[5\text{-}1000nm]}$ = 1.6E8 particles/cm3



PM Dependence on Coolant Temperature

Thermo-gravimetric Analysis	
	PM Mass Fraction (%)
Light Organic	66.0
Heavy Organic	8.5
EC	25.5

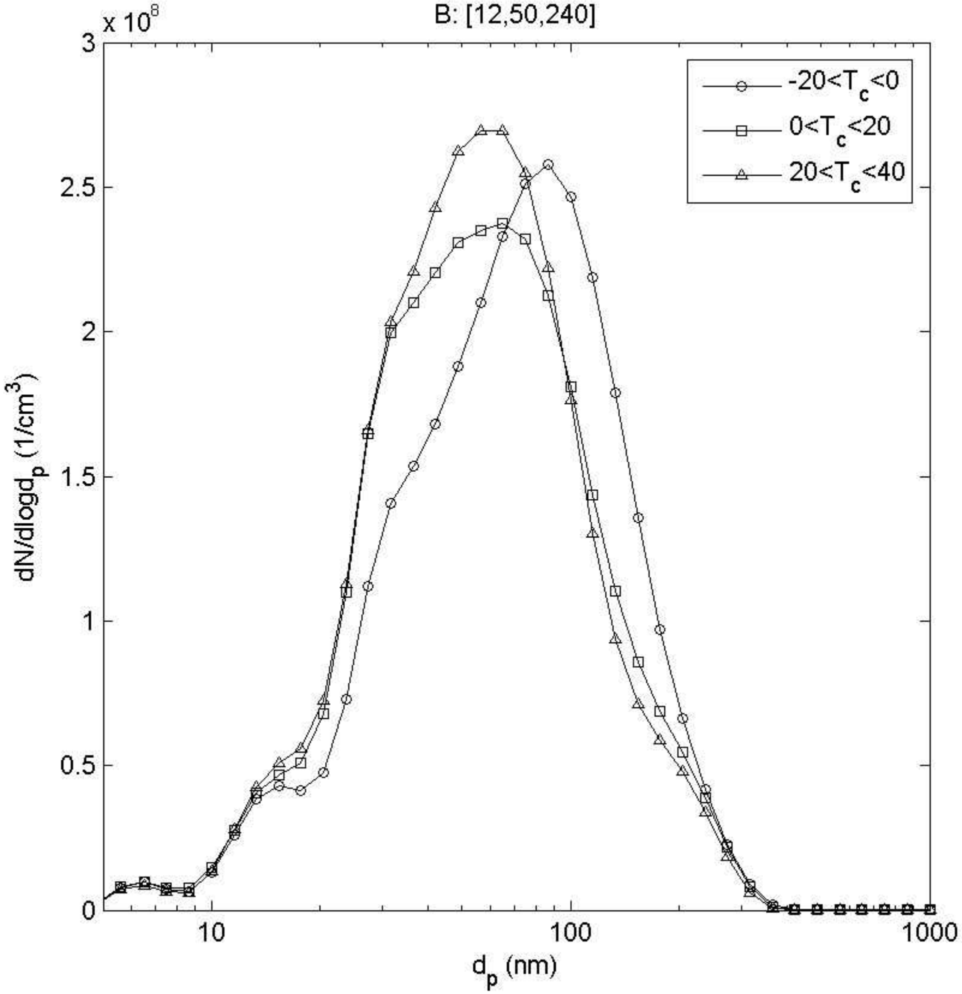
$N_{[5\text{-}1000nm]}$ = 1.8E8 particles/cm3



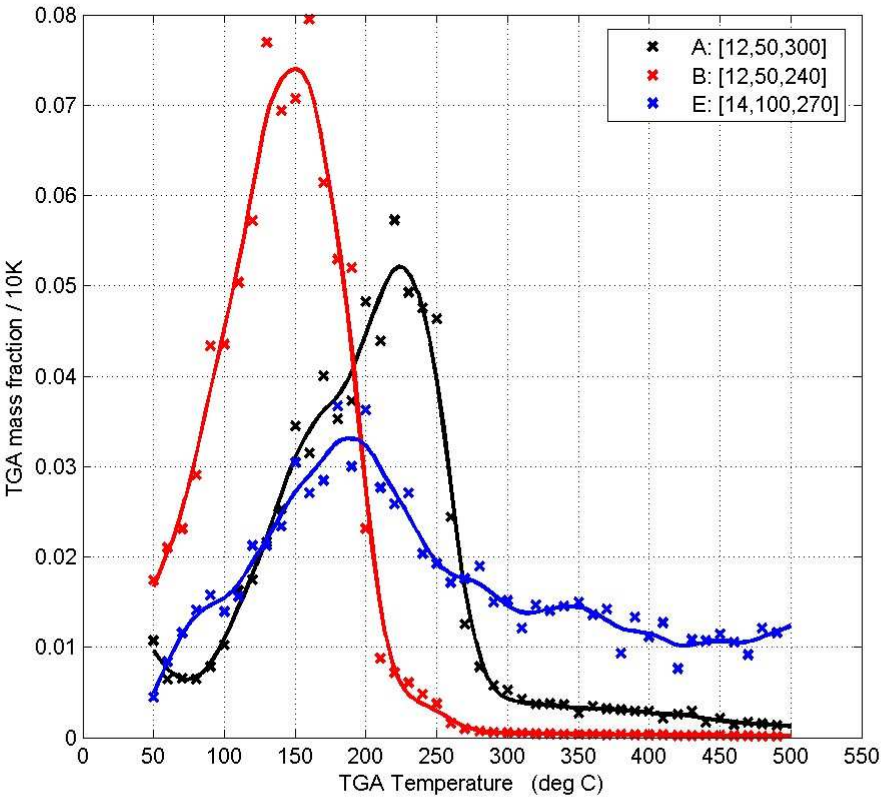
PM Dependence on Coolant Temperature

Thermo-gravimetric Analysis	
	PM Mass Fraction (%)
Light Organic	92.8
Heavy Organic	1.1
EC	6.1

$N_{[5\text{-}1000nm]}$ = 1.9E8 particles/cm3



Thermo-gravimetric Analysis of Volatile PM

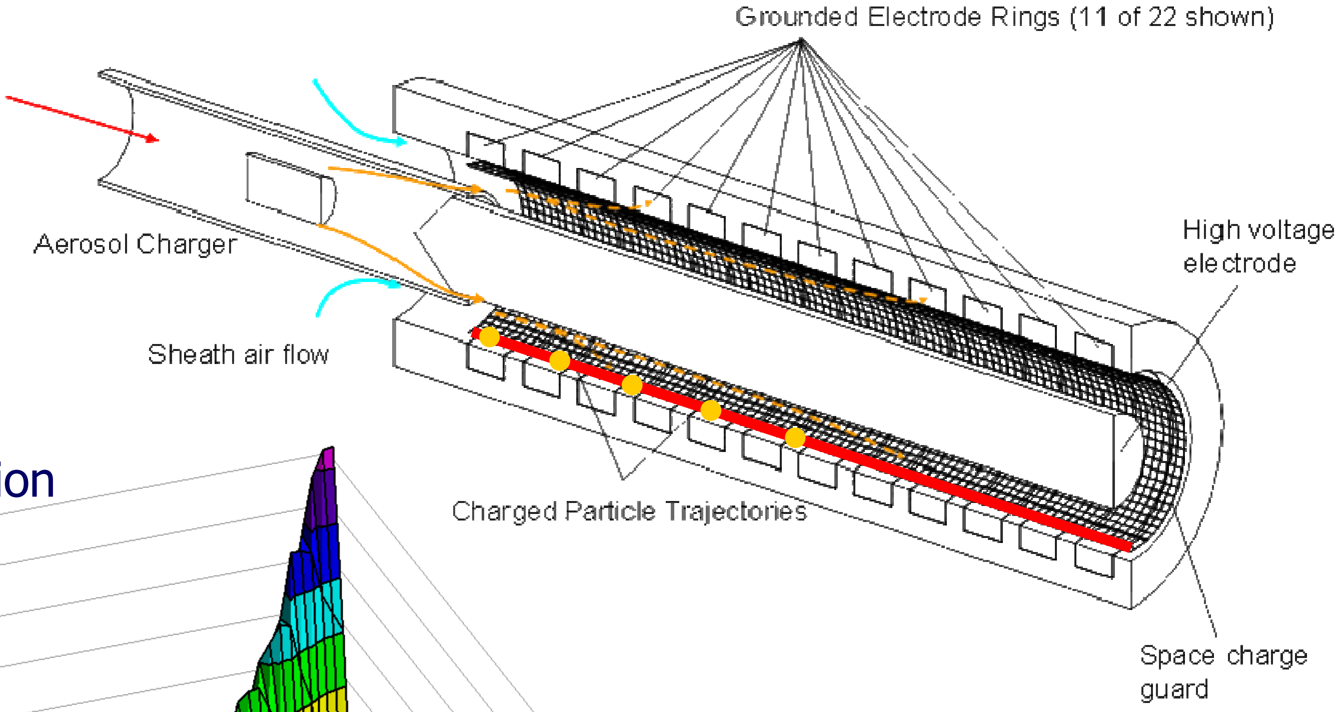


PM Mass Fraction (%)			
	A [12,50,300]	B [12,50,240]	E [14,100,270]
Light Organic	66.0	92.8	44.3
Heavy Organic	8.5	1.1	42.9
EC	25.5	6.1	12.7

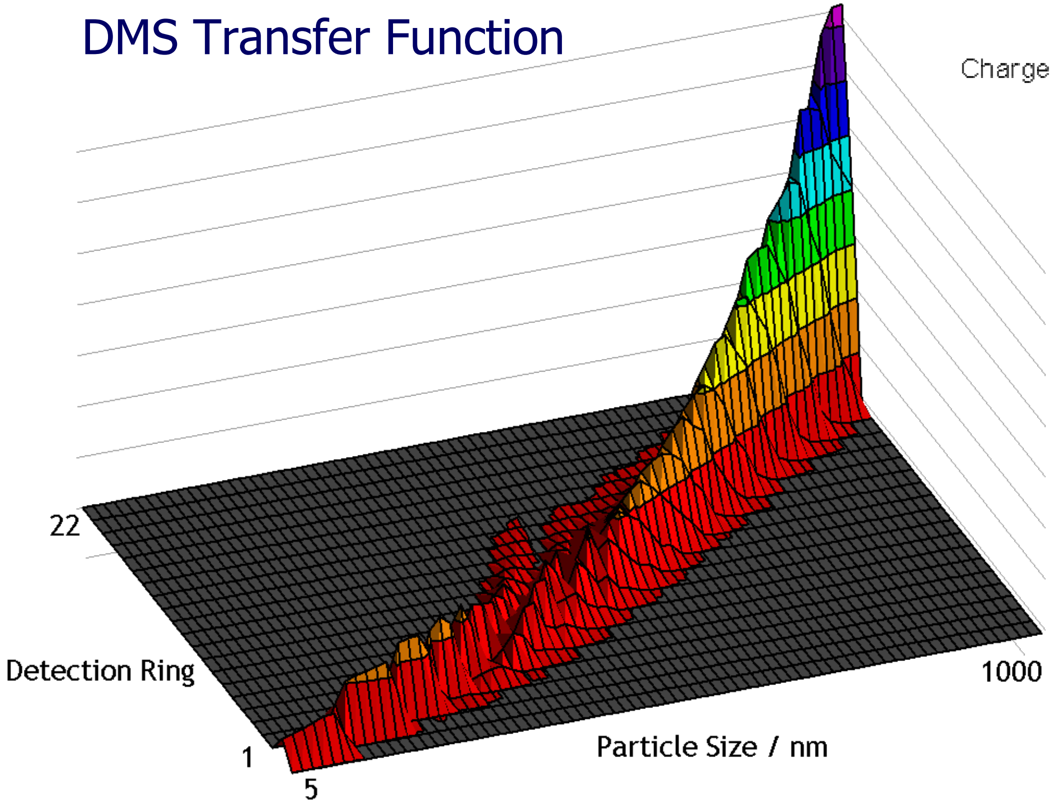
-Normalised with total volatile mass

- Dominated by light material (leaves TGA ~< 300 degC)

Space Charge Guard Modifications



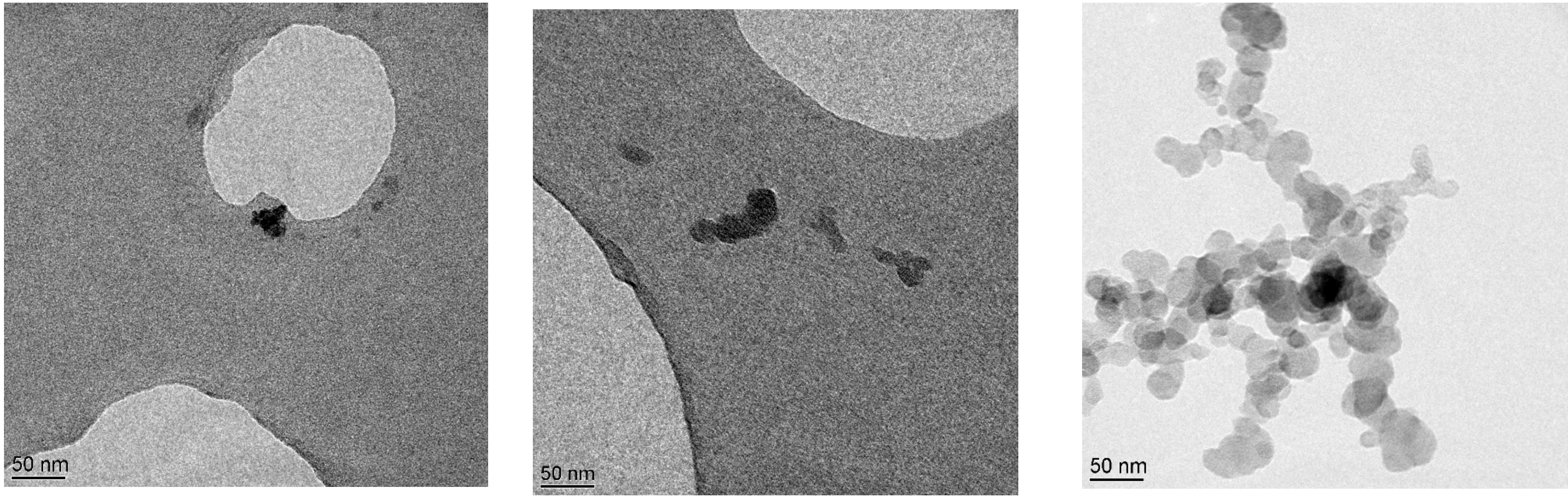
DMS Transfer Function



SCG seam modified to allow the mounting of TEM grids

Going to see a distribution because of multiple charging effect

High Res Transmission Electron Microscopy



Transmission Electron Micrographs of Sub-micron particles from gasoline combustion.

Shown: Elemental Carbon Particles.

Not Shown: Volatile Organics

Inorganics: Sulphate and Nitrate anions, ash residues (metals)

Conclusions

DI Gasoline Engine, Cold Start, Full Load
PM Measurements made with DMS500, TGA and TEM

- Thermo-gravimetric analysis showed that the composition of the emitted PM was dominated by volatile material. The elemental carbon fraction did not exceed c30 percent of the total PM by mass.
- Transmission electron microscopy confirmed the presence of a variety of solid particles, ranging from a c20 nm in diameter for single particles to a few hundred nm for aggregates. Elemental carbon particles of both amorphous and partly graphitised microstructures were detected.
- Following a cold start from -10 °C, PM number concentration generally decreased with increasing coolant temperature, by up to an order of magnitude.
- Summary: PM emissions were dominated by condensed material and having particle sizes of generally less than 100 nm.

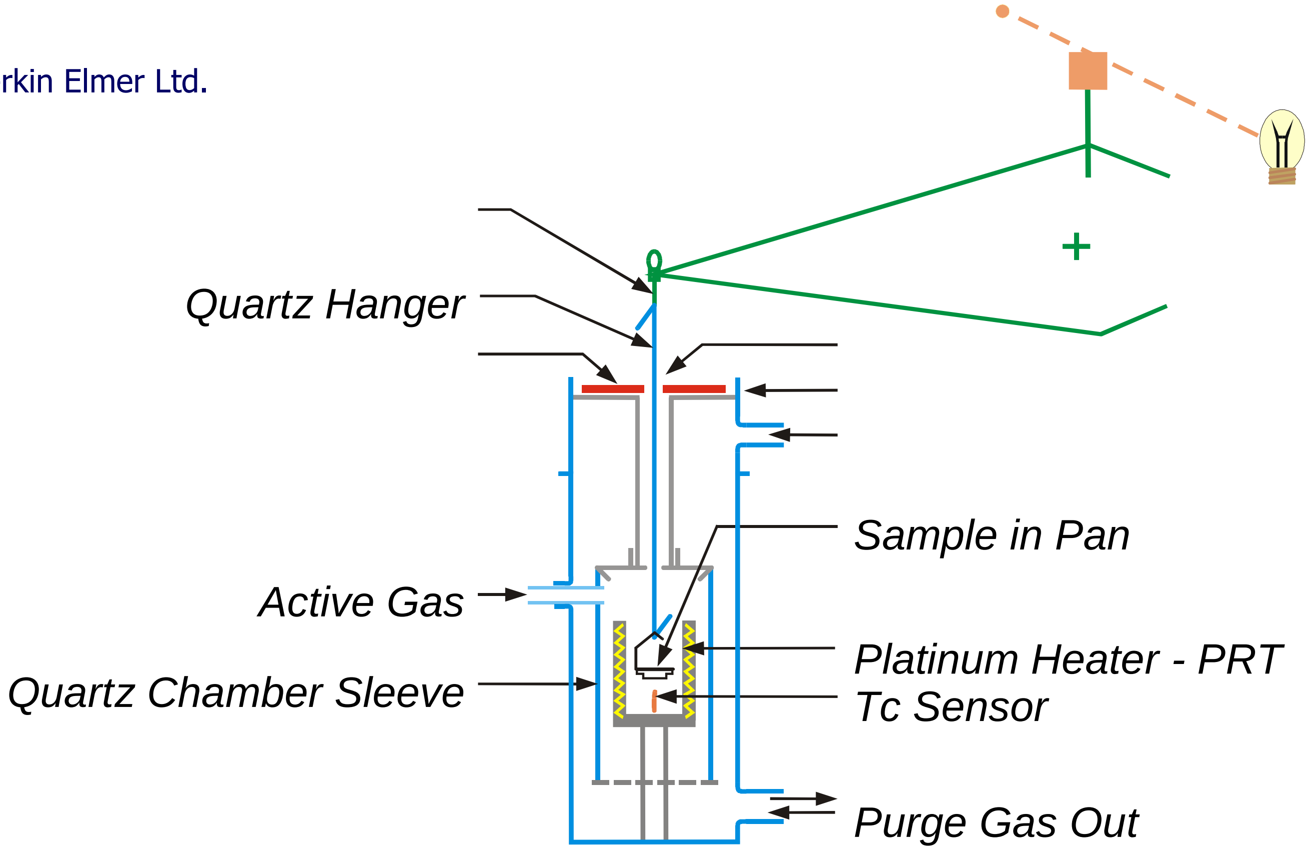
Thank you for listening

Contact:

Philip Price
Philip.price@eng.ox.ac.uk
01268 404581

Thermo-Gravimetric Analysis

Diagram courtesy of Perkin Elmer Ltd.



Temperature ramp: 50 degC/min

Measure mass decrease as f(T) in inert atmosphere to get VOF mass fraction

Change atmosphere to an oxidising one to get EC mass fraction.

Results: Gas Phase Emissions