Calibration of Fast Electrical Mobility Spectrometers for Engine Particulate Measurement

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Content of Talk

- Principle of DMS type Fast Particulate Size Spectrometer
- Calibration Procedure
  - Gain (concentration)
  - Size
- Relative charging of simple & agglomerate particles
- Effect on DMS calibration
- Application of dual agglomerate: spherical calibrations with automatic mode identification
- Comparison of mode identification with proposed PMP R83 volatile particle remover + particle counter
- Conclusions
DMS Principle of Operation

- Unipolar diffusion charger
- Electrometer detection
- Sizing by charge: drag ratio - electrical mobility

DMS Calibration Procedure

Gain Calibration
- Comparison with aerosol electrometer
- Single-charged particles of desired size selected in DMA
  - Requires small aerosol – renucleated $\text{H}_2\text{SO}_4$ and NaCl
- Traceable to calibration of electrometer & flowmeter
- Better than CPC standard
  - only reliable in count mode, ∴ differential dilution required, with uncertainty

Size Calibration
- Small sizes – calibration against DMA (mobility standard)
- Larger sizes (prone to multiple charging issues in DMA) – certified PSL spheres
  - requires good size resolution

- Information incorporated into transfer function used in deconvolution of electrometer currents
Charging of Agglomerate Particles

- Size classification by charge: drag ratio
- Concentration measurement by electrical current
- Measurement sensitive to charge distribution of particles.
1. Simple Particles

2. Diesel Agglomerates

‘Charge Distribution Produced By Unipolar Diffusion Charging of Fine Aerosols’; Reavell, Symonds & Biskos. Conf. AAAR 2004
Unipolar Diffusion Charging Comparison
- simple particles vs. agglomerates

DMS500 Mean Particle Charge

~dp^{1.25}

~dp^{1.06}

Combustion agglomerates:

Simple particles:

- NaCl / ejector pump
- DEHS / peristaltic pump
- Diesel, 4th Gear 70kph
- Diesel, 5th Gear 70kph
Similar charging behaviour for both engine loads
Combustion aerosol generator also similar
Possible small differences at very top of size range
Difference between spherical & agglomerate particles causes errors in measurements of larger agglomerate particles made with a calibration for spherical ones

- due to coupling of size & concentration measurements
Mode identification software replaces continuous spectrum with 6 parameters:

<table>
<thead>
<tr>
<th>Nucleation</th>
<th>Accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMD</td>
<td>GMD</td>
</tr>
<tr>
<td>GSD</td>
<td>GSD</td>
</tr>
<tr>
<td>N/cc</td>
<td>conc</td>
</tr>
</tbody>
</table>

Bayesian algorithm identifies modes significantly above noise base of instrument, and identifies whether accumulation or nucleation mode.

- Reduces noise in measurements by increasing data redundancy (6 vs 38 DoF)
- Removes cross sensitivity introduced by crude size cut-off methods
- Improves spectral resolution – also improves calibration accuracy with PSL spheres

Algorithm operates directly on electrometer current data:

- Different transfer functions can be used for the two modes
Real-time Mode Identification - transient vehicle test

Standard Inversion Method

Nucleation Mode

Accumulation Mode
Validation of Accumulation Particle Number Measurement

- Peugeot 406 HDi 2.2l common rail diesel vehicle (no DPF, with DOC).
- Compare DMS500 accumulation mode number concentration with output from PMP-like CPC + VPR system
  - CPC + VPR equivalent system measurements corrected with true solid particle penetration measured with NaCl (not in proposed standard)
  - CPC TSI 3022 (ie. non PMP-compliant lower size threshold)
- DMS500 accumulation mode calibrated with miniCAST aerosol, (DMA & Electrometer)

Tests under no load:
- Ejector diluter in tailpipe, DF ~ 4.7
- Idle, fast idle, transient and high-rev (U.K. “MOT test”) conditions
- CPC “REF” used post PND1 to measure nucleation mode concentration

Tests under load:
- Chassis dynamometer
- CVS tunnel used
- New European Drive Cycles
PMP equivalent dilution system

ET effectiveness measured at 99.7% with $\text{H}_2\text{SO}_4$ with $T_1 = 50^\circ\text{C}$
No Load Transient Cycle: Real-time comparison DMS vs CPC + VPR

DMS & CPC Measurement of Nucleation & Accumulation Modes
No Load Total Emissions Comparison: DMS Accumulation Mode vs. CPC + VPR

Solid particle number data corrected to pre-PND1 and averaged per second.

- Mean DMS accumulation ~ CPC +9%
- Mean DMS spherical cal ~ CPC +44%
Loaded Transient Tests: NEDC on Dynamometer (1)
NEDC on dynamometer: Repeats

**Graph**

- **Y-axis:** N / km
- **X-axis:** Test
- **Legend:**
  - Red: N / km DMS
  - Blue: N / km PMP

**Data Points**

- **Test 1:**
  - N / km DMS: 8E+13
  - N / km PMP: 6E+13

- **Test 2:**
  - N / km DMS: 7E+13
  - N / km PMP: 5E+13

- **Test 3:**
  - N / km DMS: 6E+13
  - N / km PMP: 5E+13
- Same vehicle with DPF fitted
- Direct sampling post-DPF with DMS500
- Newly regenerated DPF
- Total particle number from DMS would fail proposed standard
- With automatic mode identification, accumulation mode emissions correctly resolved below limit.

<table>
<thead>
<tr>
<th>Acc Mode N / km</th>
<th>Nuc Mode N / km</th>
<th>Total N / km</th>
<th>Proposed PMP limit N / km</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.9 \times 10^{11}$</td>
<td>$1.4 \times 10^{12}$</td>
<td>$1.6 \times 10^{12}$</td>
<td>$5.0 \times 10^{11}$</td>
</tr>
</tbody>
</table>
Conclusions

- A traceable calibration procedure based on comparison with an aerosol electrometer for gain and PSL spheres for size calibration is described for DMS type instruments.
- Combustion agglomerates are more highly charged in the DMS unipolar charger ($\sim d_p^{1.25}$) than simple particles ($\sim d_p^{1.06}$).
- This affects both the size, and particularly, concentration measurement of agglomerate particles in electrical mobility based sizing instruments.
- A calibration for agglomerate particles which can be automatically applied to just the accumulation mode of an exhaust aerosol is demonstrated and compared with a PMP-like CPC + VPR measurement system.
- The average difference between the CPC+VPR measurement and agglomerate calibrated DMS is $\sim 9\%$ on engine exhaust aerosols.
- The automatic mode identification allows the DMS to measure accumulation mode levels in the presence of significant nucleation concentrations.
- There are significant differences between nucleation concentrations measured with the DMS and by differencing two CPCs.
Thanks to Bruce Campbell, Roy Stubbs and Paul Davies for the dynamometer testing.

And to the organising committee of the conference.

Questions?