A COMPARISON OF AEROSOL INSTRUMENTS TO REGULATED PM/PN EMISSIONS FROM GDI AND PFI VEHICLES

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Discrepancies have been reported between data collected by EEPS (and FMPS) and SMPS: Jeong and Evans 2009; Asbach et al., 2009; Zimmerman et al., 2014; and others.

In general, particles larger than ~80 nm are undersized by EEPS using “Default” matrix

Resulting in:
- Narrower size distribution
- Smaller mean diameter
- Reduced concentration of large particles (large particle “roll off”)

Solution: New instrument matrices - empirically calibrated
Difference in measurement principle is cause for discrepancy

+ SMPS: Bipolar neutralizer- morphology independent
+ EEPS: Unipolar charger- higher charge state, morphology dependent

• Unipolar charger necessary to achieve electrometer signal above background noise
• Particle morphology dependent charging characteristics complicate charge state to particle size correlations
• Challenge: distinguishing large particles with more charges from small particles with fewer charges
Bipolar versus unipolar charging

**Bipolar**
+ Used in SMPS
+ Dominated by ion diffusion
+ Largely independent of particle morphology
+ **Predictable**

**Unipolar**
+ higher charge than bipolar
+ ion diffusion *and* electrostatic forces
+ **morphology dependent**
  - surface area
  - capacitance
  - Agglomerates ~30% more charge\(^1,2\)
+ steady-state charge **unpredictable**

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\(^2\)Biskos et al. (2005) paper "Description and Theoretical Analysis of a Differential Mobility Spectrometer" in AS&T 39: 527–541
Summary of alternative EEPS inversion matrices

+ Two new matrices developed by TSI and Xiaoliang Wang of Desert Research Institute (DRI) with the help of the University of Minnesota Center for Diesel Research (CDR)
  • Developed by empirically calibrating EEPS to SMPS
+ “Soot” matrix for agglomerates like engine exhaust
+ “Compact” matrix for compact (near spherical) aerosols
+ “Default” matrix developed in 2004 by Aadu Mirme of Tartu University
  • Based on theoretical and experimental data from different aerosol types
Development of EEPS matrices

1. Polydisperse aerosol generated
2. Monodisperse aerosol classified at EEPS primary channel diameters
3. Aerosol simultaneously measured with EEPS, SMPS, and CPC
4. EEPS data corrected for multiple charges
5. Inversion matrix, $H_{j,i}$ is determined.

\[ I_j = H_{j,i} f_i + u_j \]

Inversion matrix, $H_{j,i}$ relates particle size distribution, $f_i$ to electrometer currents, $I_j$ and offsets, $u_j$. 
Comparison of Instrument matrices

EEPS Instrument Matrix Comparison
EEPS Inversion Matrix Value (fA cm$^3$)

Electrometer Number

- 42 nm IM-Default
- 420 nm IM-Default
- 42 nm IM-Compact
- 420 nm IM-Compact
- 42 nm IM-Soot
- 420 nm IM-Soot
SMPS and EEPS with Soot Matrix

Heavy-duty diesel engine

Light-duty diesel engine

GDI vehicle

+ Soot Matrix Particle size distributions compare well to GDI vehicle, light duty diesel engine or heavy duty diesel engine

Soot inversion results in broader accumulation mode
+ Soot GSD = 1.64 (agrees better with literature)
+ Default GSD = 1.52
+ Small shift in GMD
+ Particle number is largely unaffected

Measured from CVS tunnel
Soot inversion impact is same for GDI exhaust PM

+ Soot GSD = 1.9 (consistent with SMPS)
+ Default GSD = 1.6
+ GMD and particle number largely unaffected

**GDI Example**

Soot GSD = 1.9 (consistent with SMPS)
Default GSD = 1.6
GMD and particle number largely unaffected

Measured from CVS tunnel
PM mass from EEPS vs gravimetric filter method

- 6 GDI development vehicles run over FTP cycle
- Effective density – $D_F = 2.3$, $r_0 = 2$, $d_0 = 20$ nm
- Average dilution of ~20 is not optimized for LEV III / Tier 3 levels
PM mass from EEPS vs Micro Soot Sensor

EEPS mass calculated from integrated size distribution and effective density

+ ~70% correlation to Micro Soot mass continues to below 1 mg/mi.
+ Consistent with EC/OC measurements
Solid particle number from EEPS vs PMP method

EEPS solid PN calculated by bimodal fit, fraction of accumulation mode above 23nm

Likely explanation for 40% overestimate is that some accumulation particles are mostly liquid.
Conclusions

+ New matrices developed for EEPS measurement of agglomerated particles based on empirical inversion.
+ New inversion agrees well with SMPS and literature data, resulting in broader size distributions relative to default.
+ PM mass results with good correlation to gravimetric through integrated size distribution and mass mobility exponent of 2.3 for effective density.
+ Solid particle number from accumulation mode is high by ~40%, likely from some being mostly liquid.
+ Second-by-second capability of EEPS very useful for engine research, e.g. to investigate new combustion modes, cold start strategies, fuel effects, etc.
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Other references


Thank You