



*Mining Diesel Emissions Council – MDEC
October 8, 2008 - Sheraton Parkway Toronto North*

Tail-Pipe Measurements of Emissions from LD Vehicles with Diesel Engines: A Direct Comparison of Five Different Measurement Methods

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Overview



- **Campaign scope and program**
- **Instrument Setup**
- **Results**
- **Conclusions**
- **Q & A**

Campaign Program and Scope



- Test program (in cooperation with DEKRA and TÜV Nord, other instrumentation manufacturers and developers also participated)
 - 31 test runs during one week on a chassis-dynamometer at DEKRA Technology Center in Klettwitz (Germany)
 - 3 different diesel engine vehicles (all Euro 4, one w/o DPF)
 - Adjustable DPF-bypass in several tests to simulate DPF malfunction
 - European drive cycle tests as well as steady state test cycles were run
- Scope: Demonstrate that tail pipe measurements can identify DPF malfunctions which OBD can't

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Experimental Setup



Climatic Chassis Dynamometer at DEKRA Klettwitz

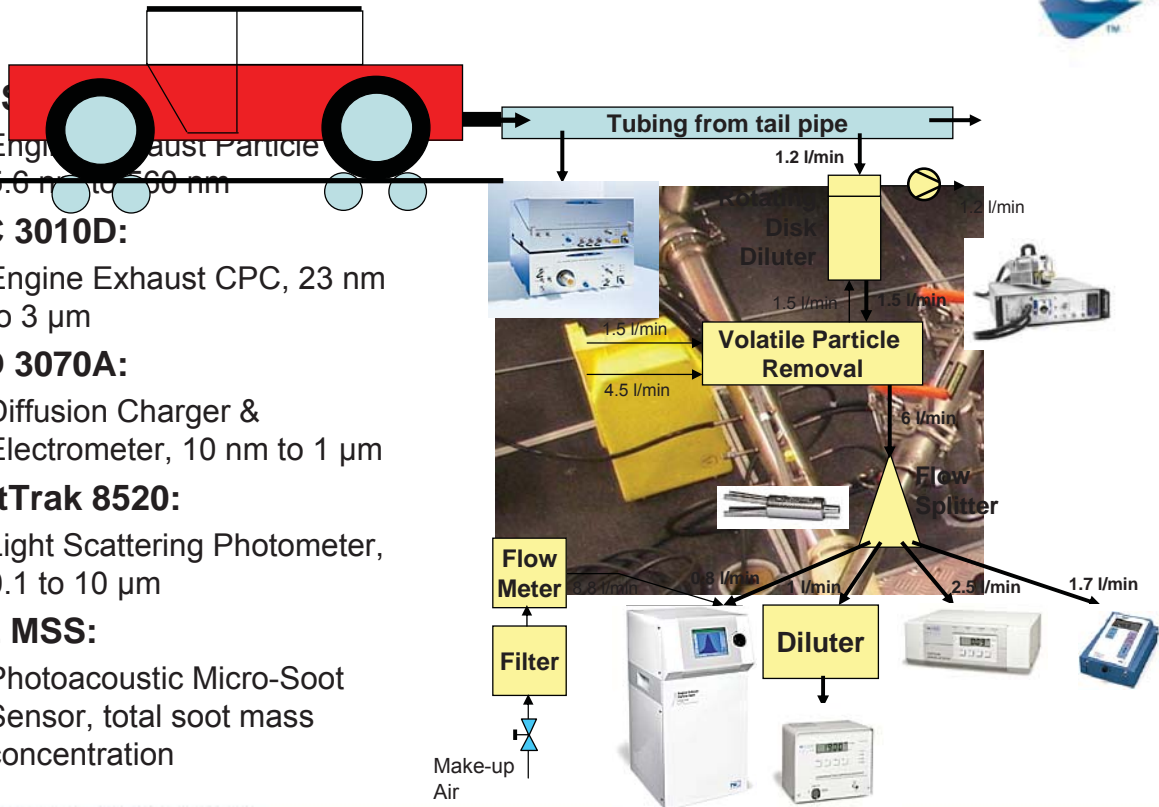
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Experimental Setup



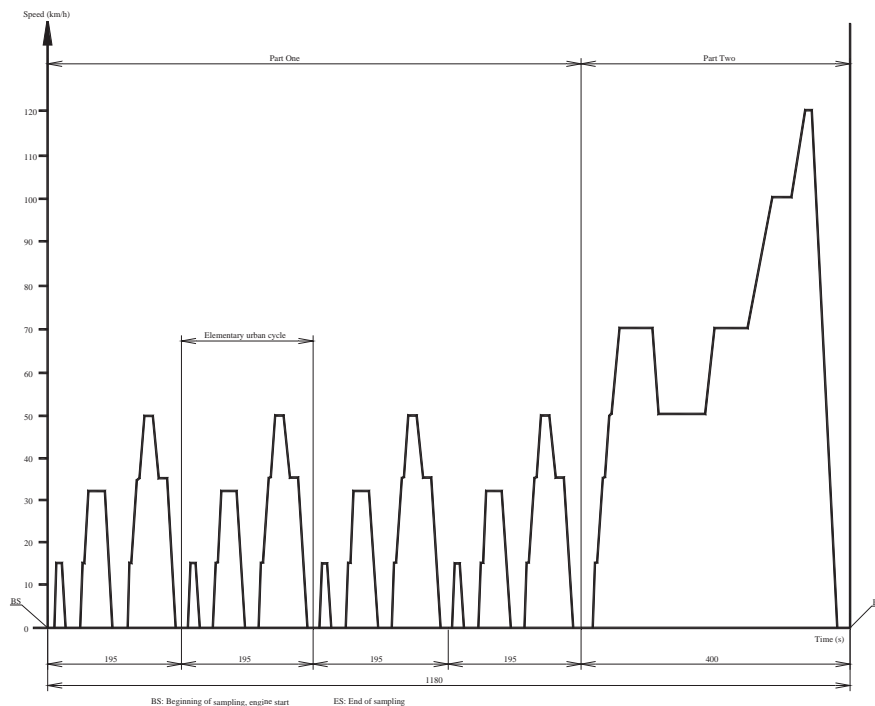
- **EEPS**
 - Engine Exhaust Particle Sizer, 5.6 nm to 560 nm
- **CPC 3010D:**
 - Engine Exhaust CPC, 23 nm to 3 μ m
- **EAD 3070A:**
 - Diffusion Charger & Electrometer, 10 nm to 1 μ m
- **DustTrak 8520:**
 - Light Scattering Photometer, 0.1 to 10 μ m
- **AVL MSS:**
 - Photoacoustic Micro-Soot Sensor, total soot mass concentration



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Operating cycle for the Type I test



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Data Analysis

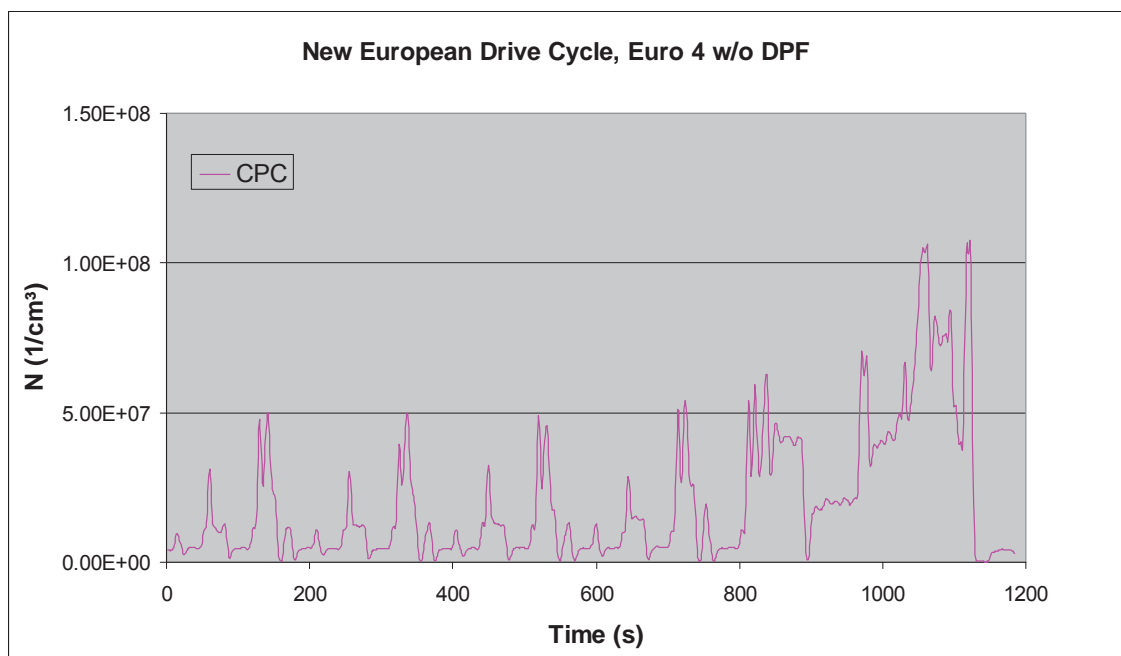
- Step 1:
Synchronize all instrument data (using the first prominent peak)
- Step 2:
Apply a 5 seconds running average to all data sets to minimize the influence of instrument response time
- Step 3
Integrate each data set and normalize all number (mass) measurements to the integrated data of the CPC 3010D (EEPS 3090)
- Step 4
Compare dynamic concentration range and data correlation based on second by second data

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Particle Number

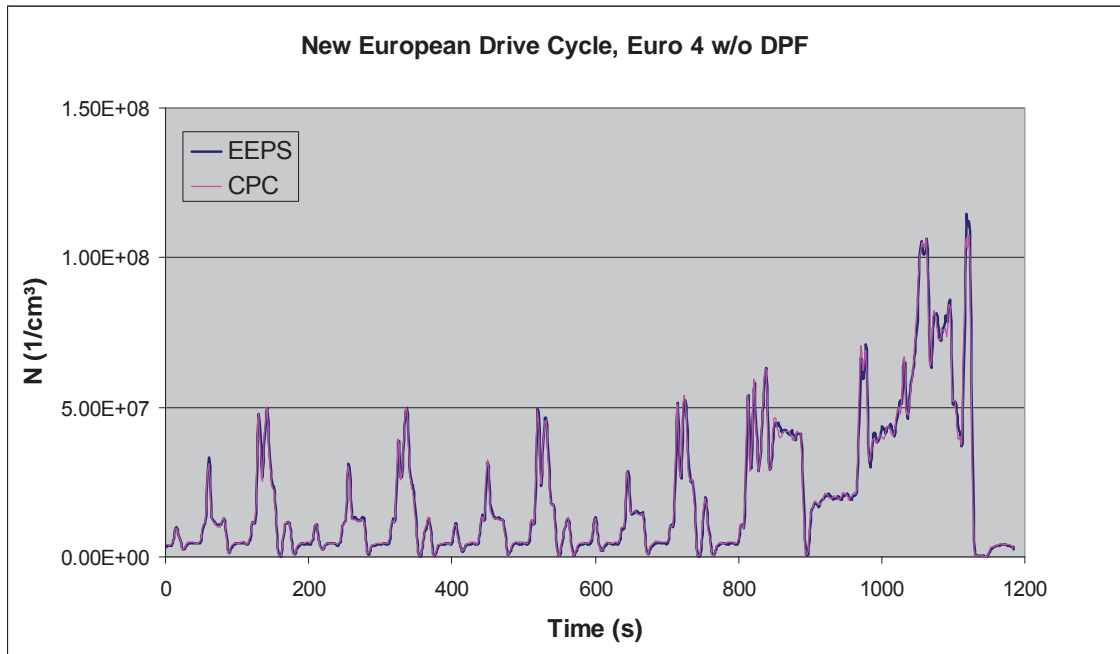


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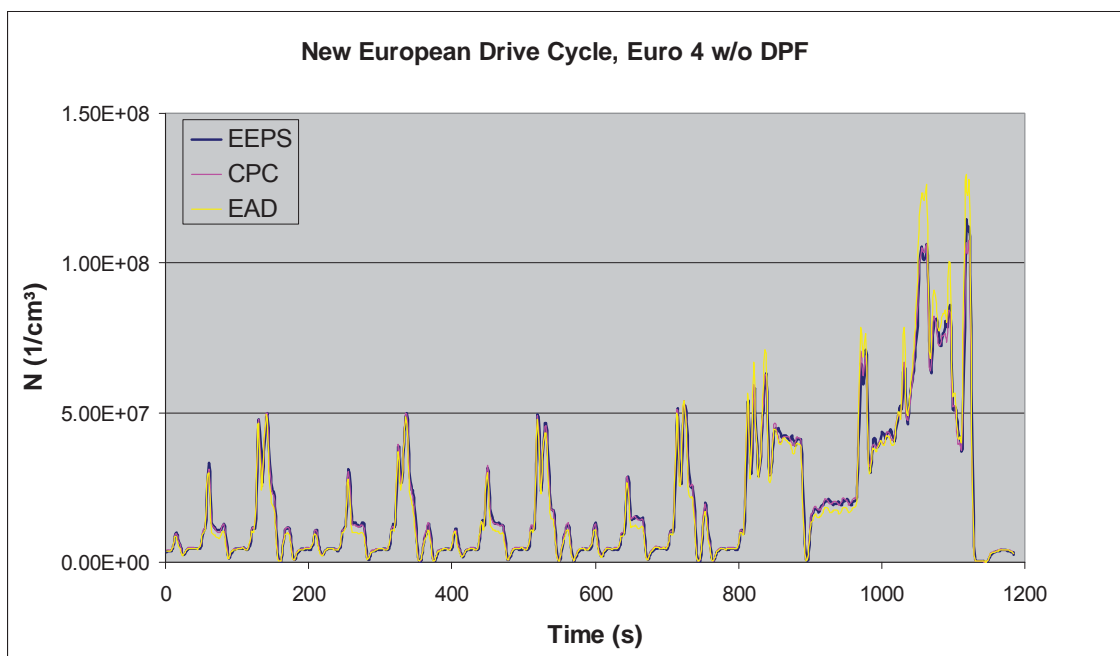


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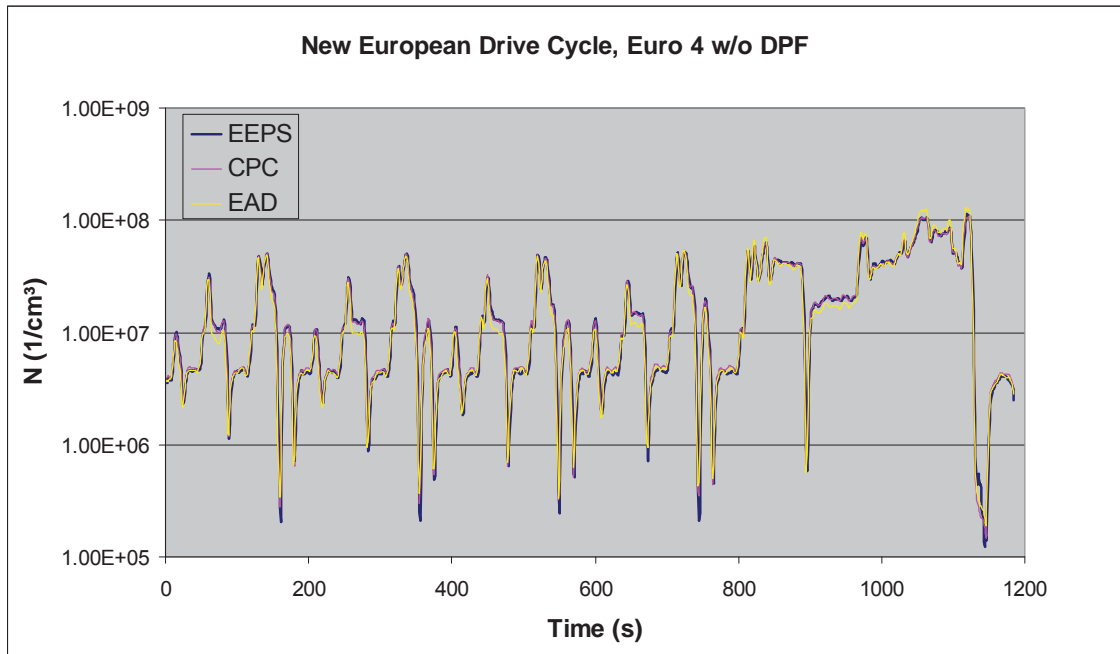


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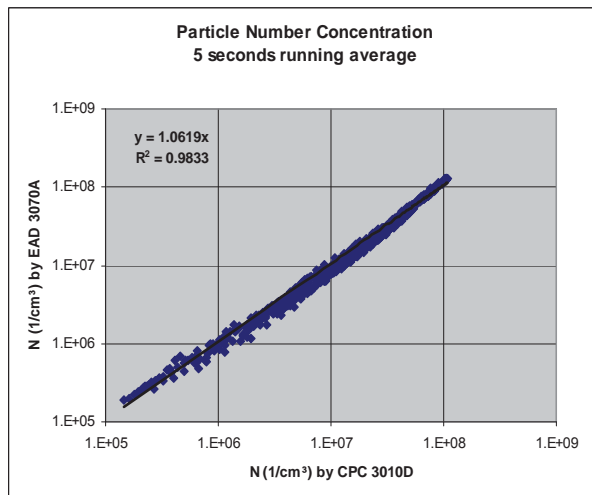
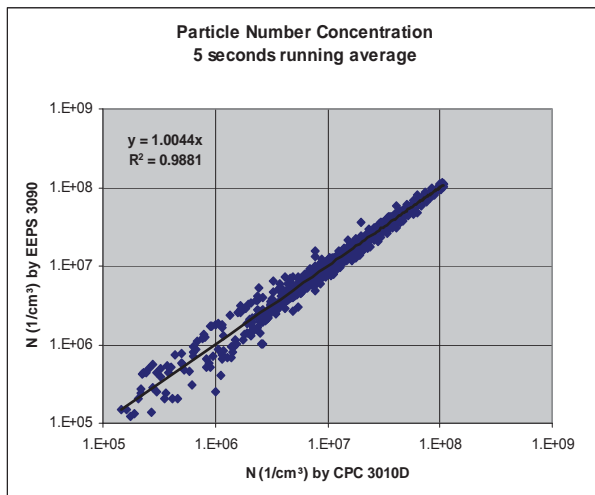


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Number Correlation

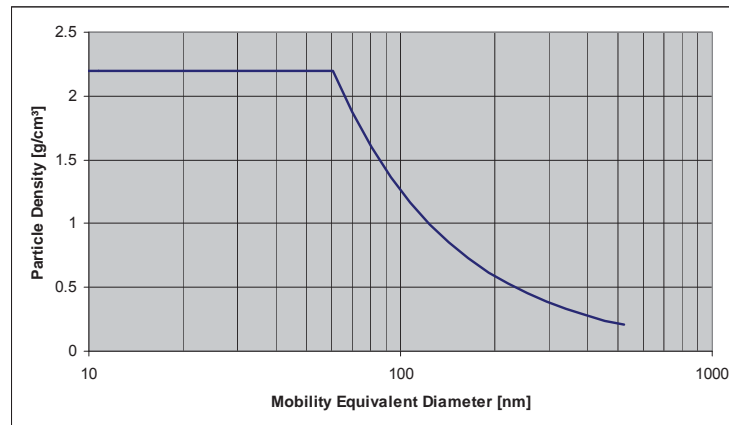


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EEPS Mass Calculation



Fractal density function for EEPS mass calculations:

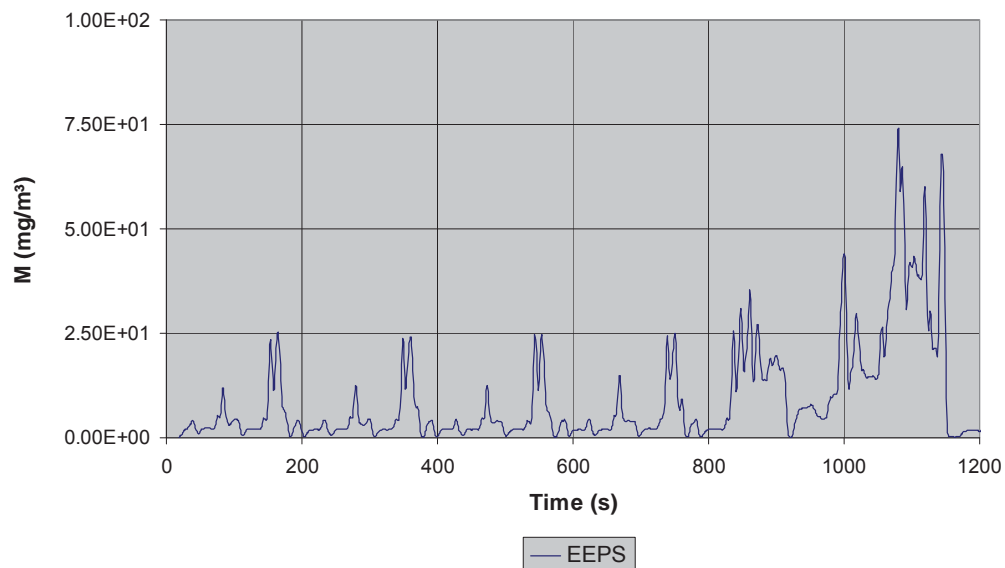
$$\rho_p \text{ (g cm}^{-3}\text{)} = C D_p \text{ (nm)}^{Df-3} ; C = 200; Df = 1.9$$

$\rho_p < 2.2 \text{ g cm}^{-3}$ estimated density of primary soot particles



Particle Mass

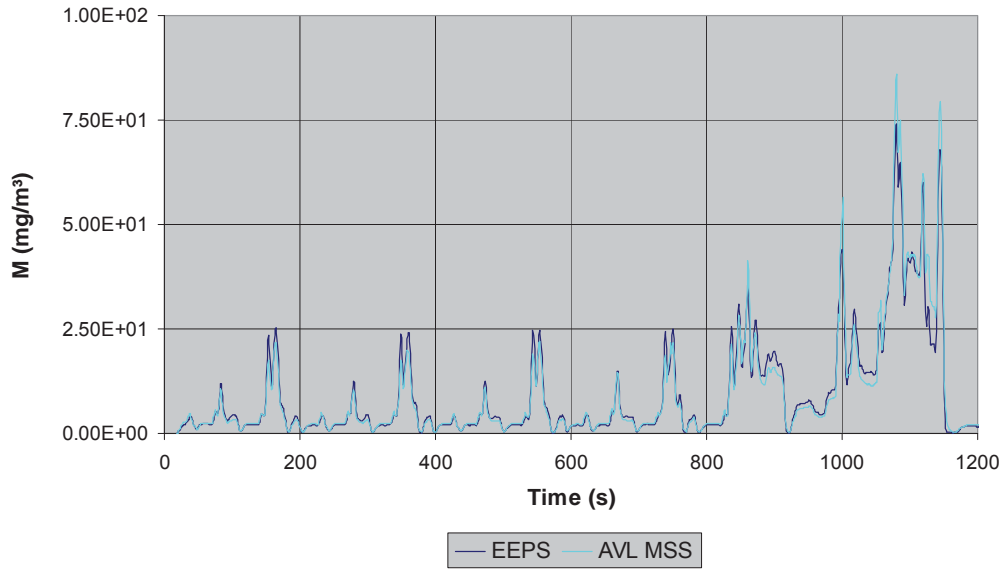
European Drive Cycle, Euro 4 w/o DPF





Particle Mass

European Drive Cycle, Euro 4 w/o DPF



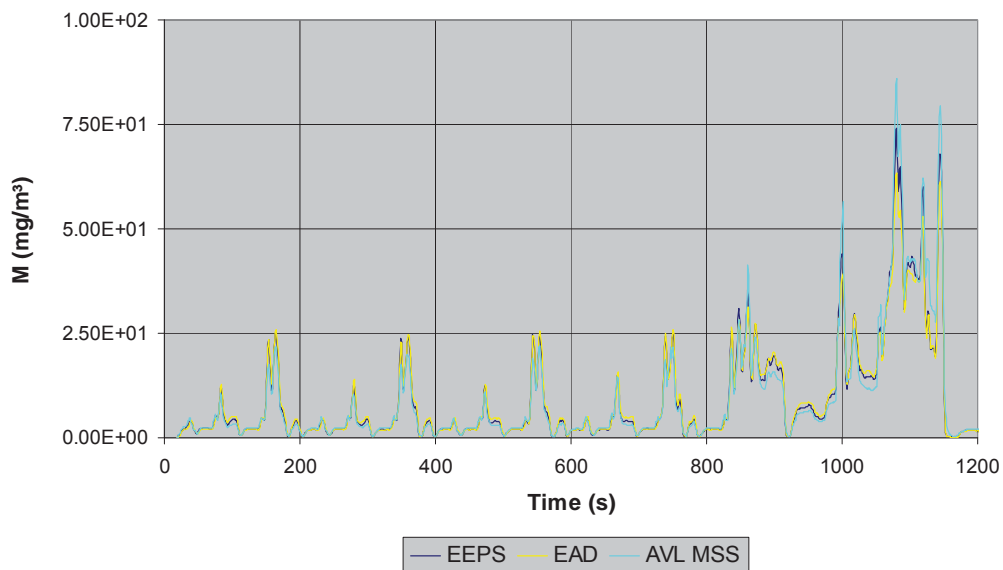
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Particle Mass

European Drive Cycle, Euro 4 w/o DPF



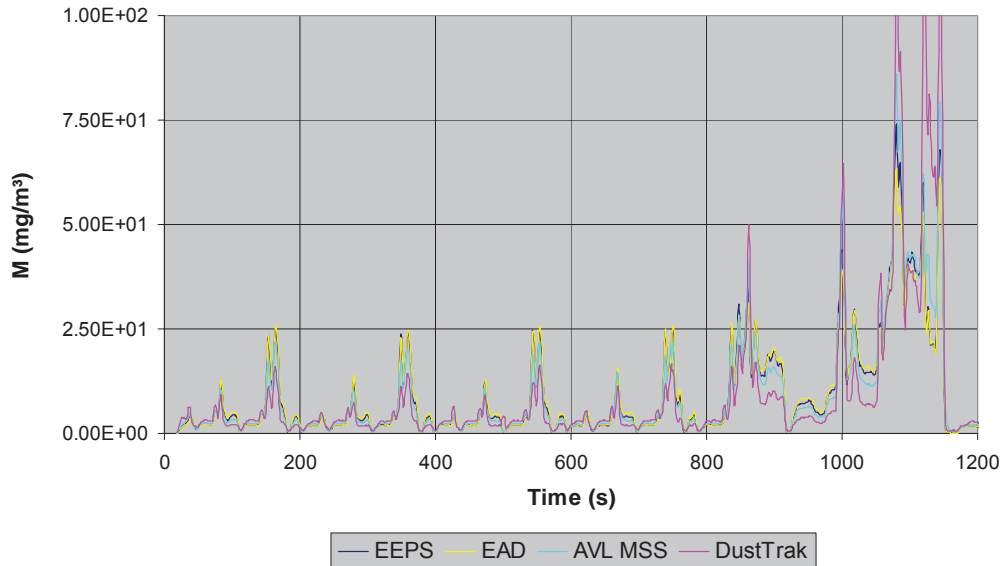
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Particle Mass

European Drive Cycle, Euro 4 w/o DPF



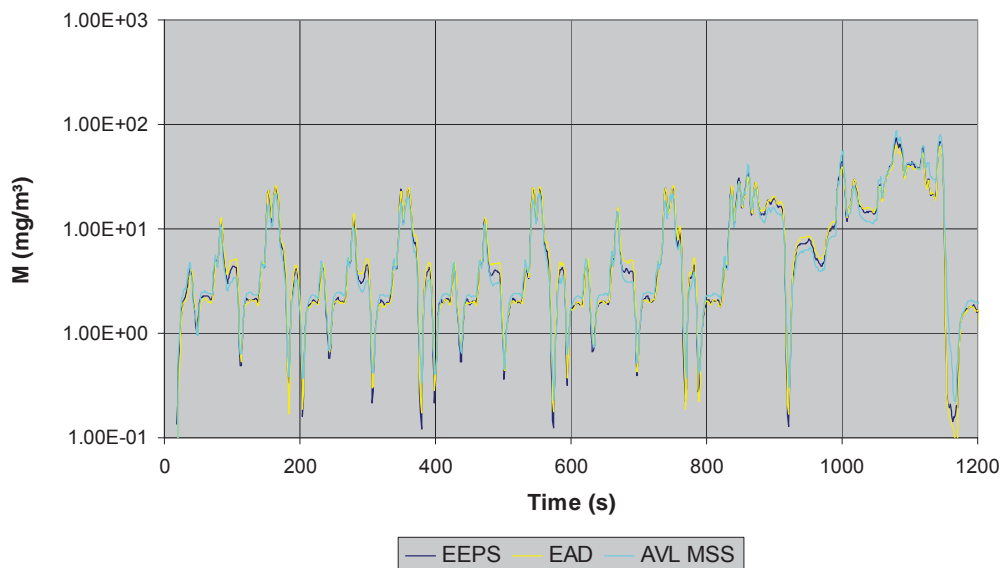
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Particle Mass

European Drive Cycle, Euro 4 w/o DPF



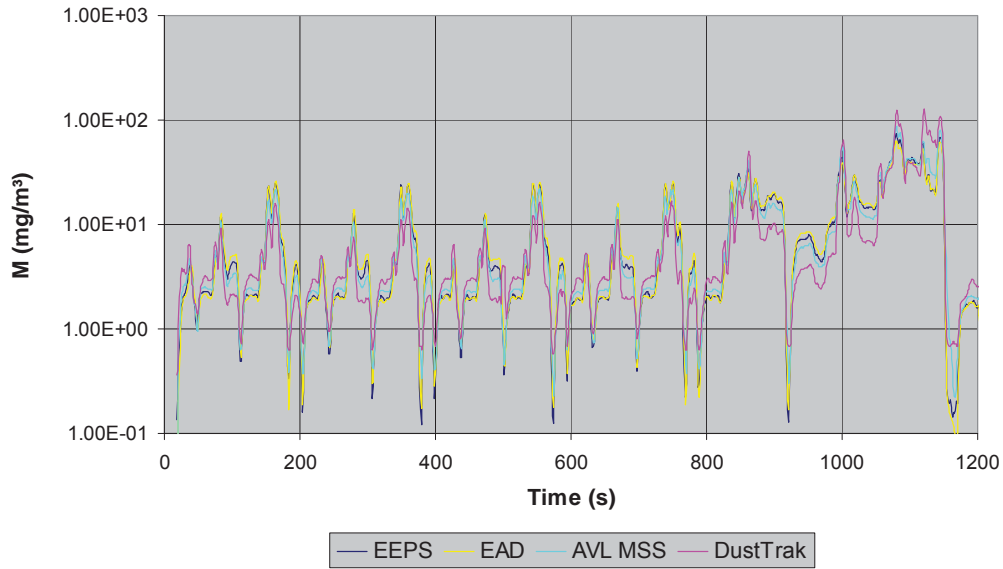
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Particle Mass

European Drive Cycle, Euro 4 w/o DPF

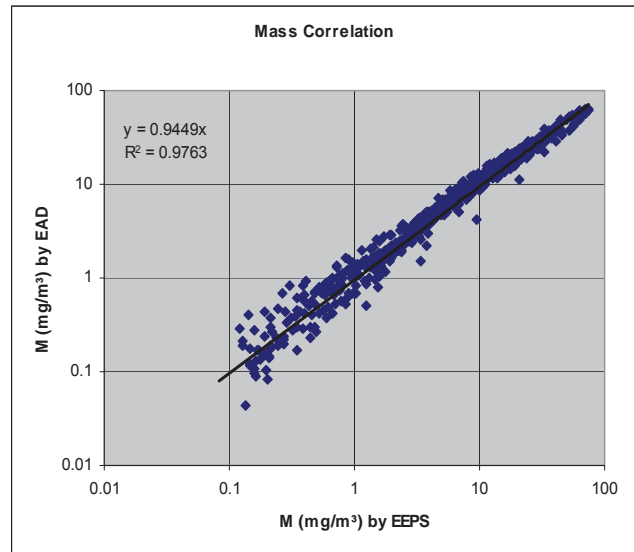
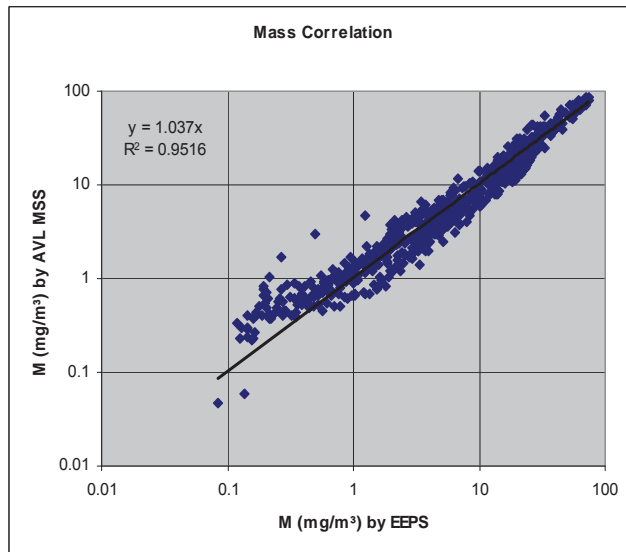


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Mass Correlations

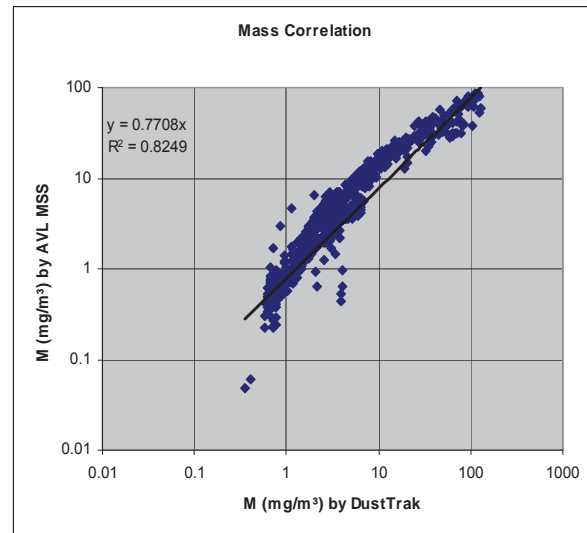
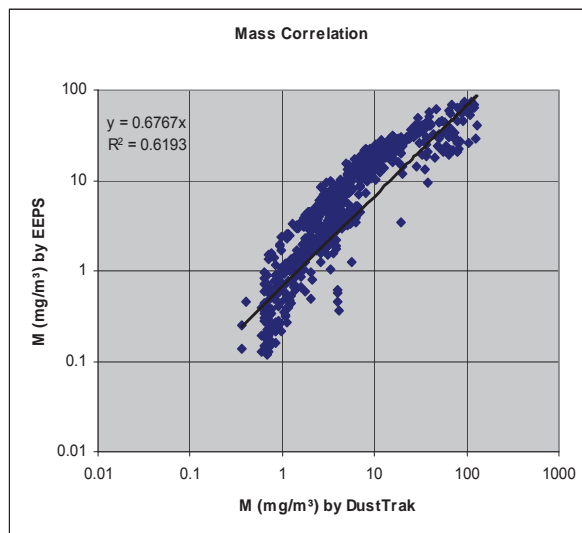


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Mass Correlations



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Overall Correlation

- Average number concentration and mass concentration was calculated for each test run
- Instruments used in the test runs were then correlated based on these average values

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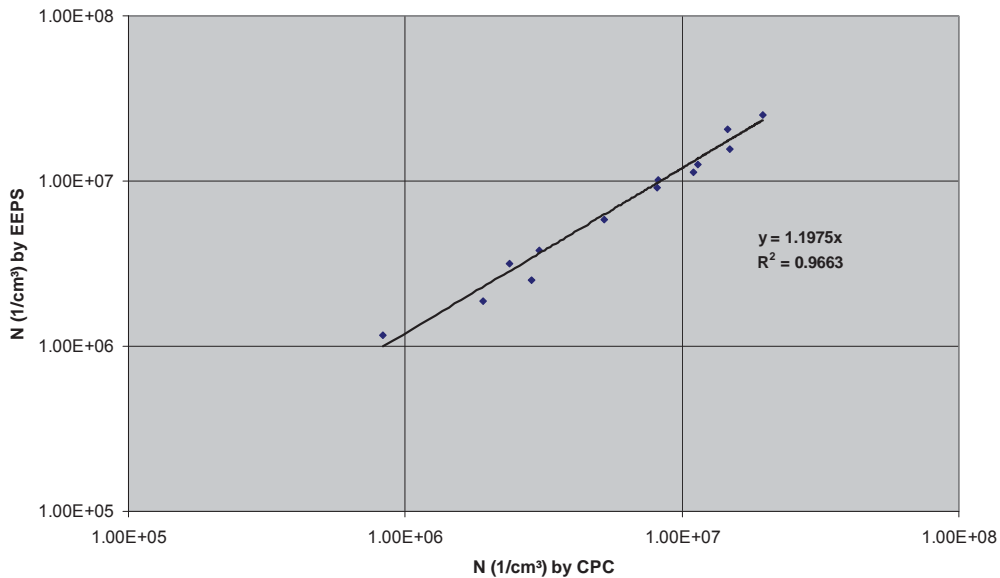
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Overall Correlations - Number

based on average data of all test runs



EEPS Number Concentration vs. CPC Number Concentration



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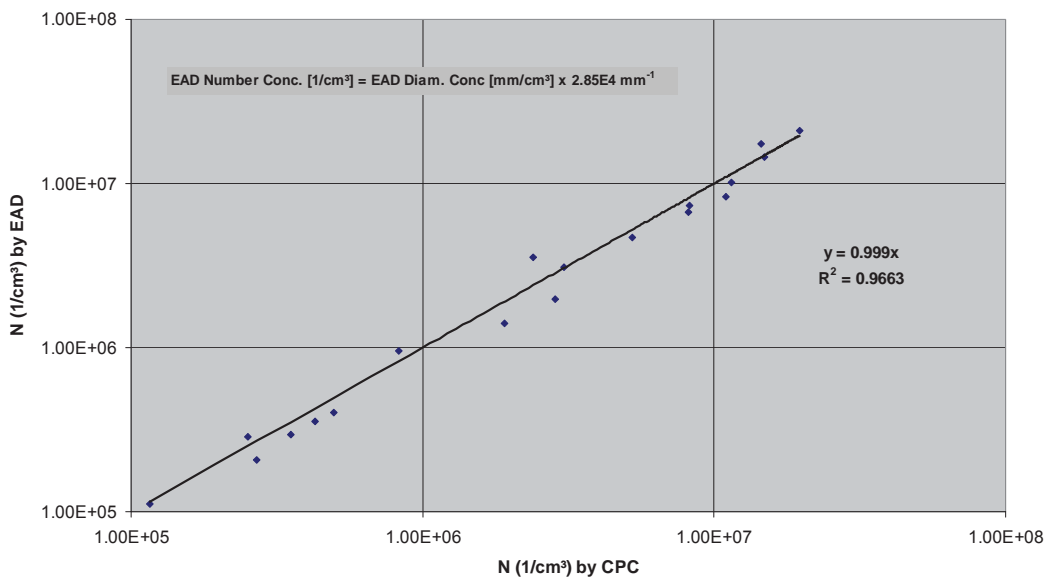
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Overall Correlations - Number

based on average data of all test runs



EAD Number Concentration vs. CPC Number Concentration



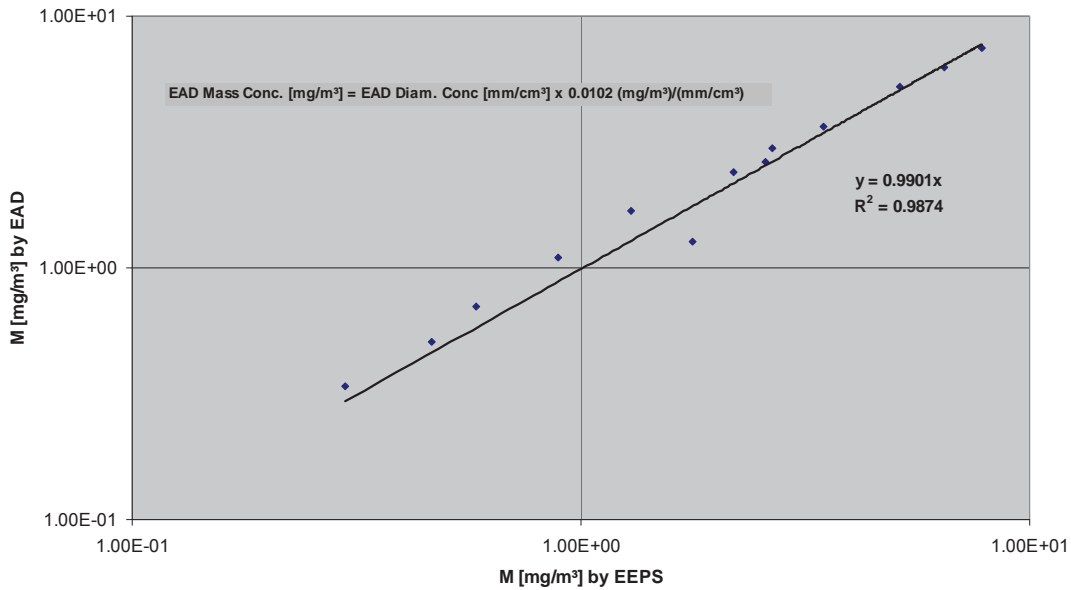
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Overall Correlations - Mass based on average data of all test runs



EAD Mass Concentration vs. EEPS Mass Concentration



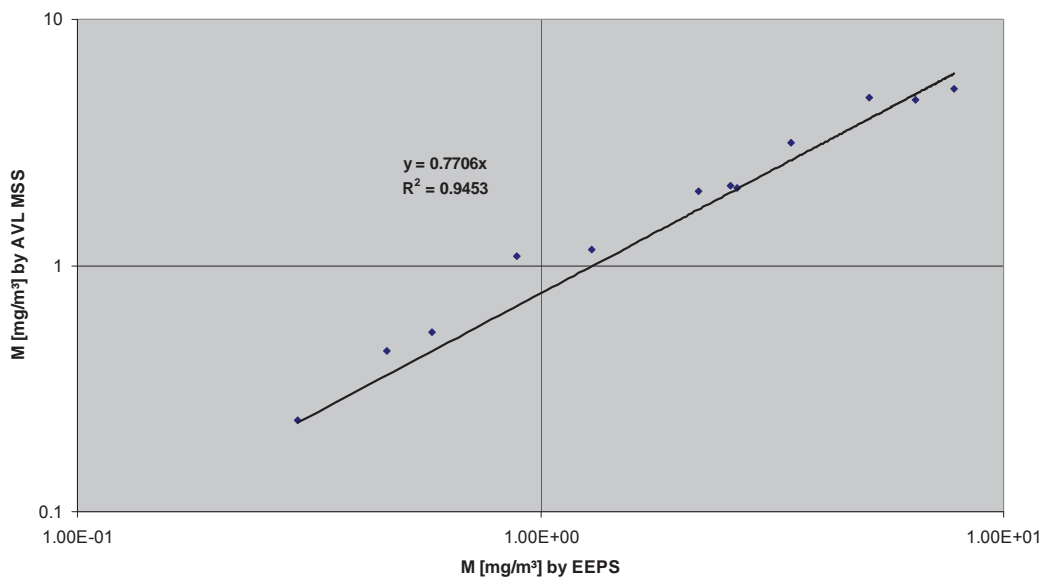
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Overall Correlations - Mass based on average data of all test runs



EEPS Mass Concentration vs. AVL MSS Soot Concentration



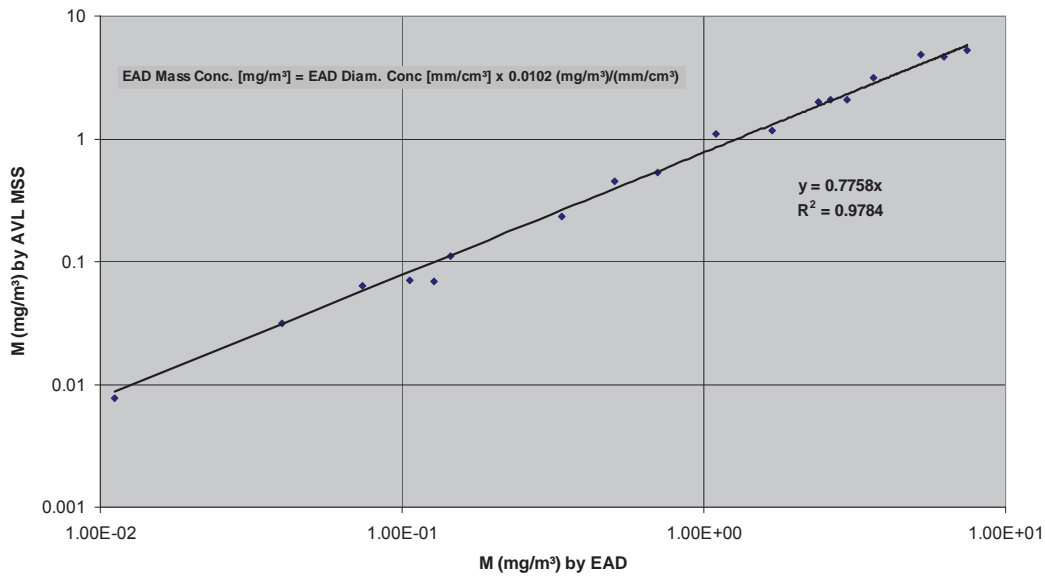
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Overall Correlations - Mass based on average data of all test runs



EAD Mass Concentration vs. AVL MSS Soot Concentration



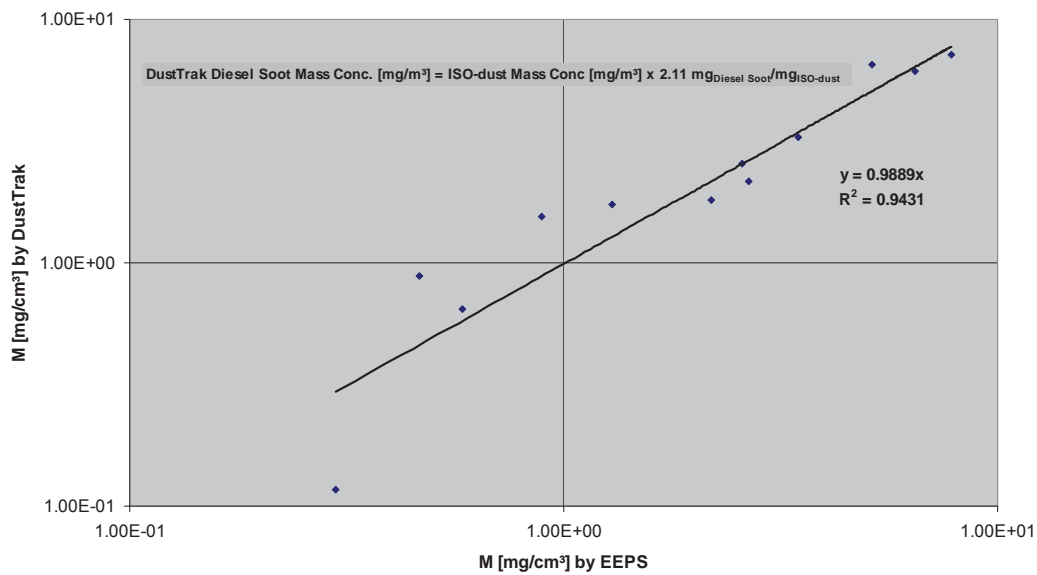
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Overall Correlations - Mass based on average data of all test runs



DustTrak Mass Concentration vs. EEPS Mass Concentration



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Conclusions

- For thermo-diluted tail pipe soot, EAD can be calibrated for number as well as mass measurement
- CPC, EEPS and EAD demonstrated the necessary sensitivity and dynamic concentration range for particle number and mass measurements
- Overall correlation for all tested methods showed R^2 ranging from 0.95 to 0.99
- Light scattering systematic dependence on size distribution shifts, other methods were fairly unbiased.



Acknowledgements

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Thank you very much for your attention!

Questions?