West Virginia University

In-line, Real-Time Particulate Matter Sensors for OBD and Exhaust After-treatment System Control Applications

CAFEE
Center for Alternative Fuels, Engines and Emissions

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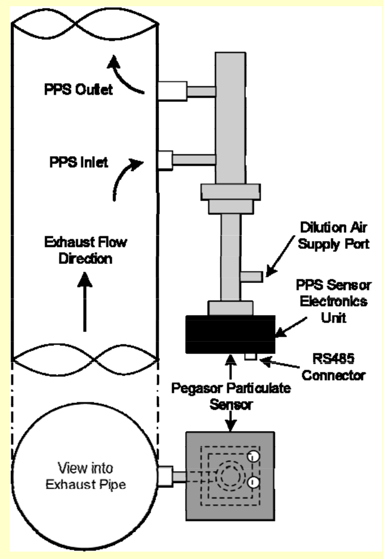
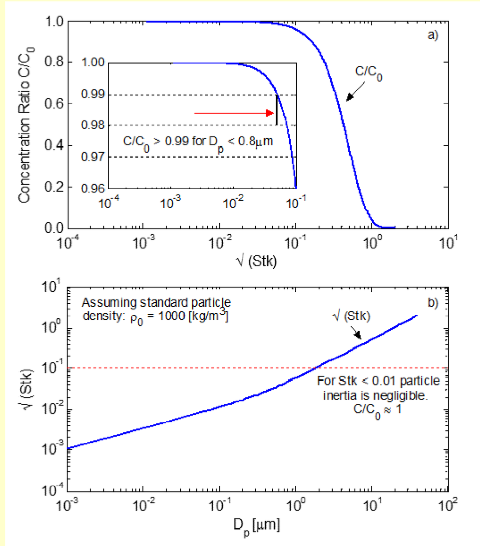
Fundamental sensor response studies - soot generator studies

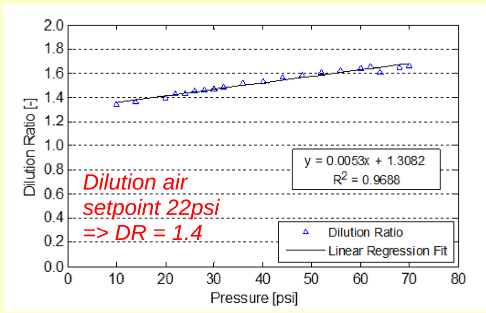




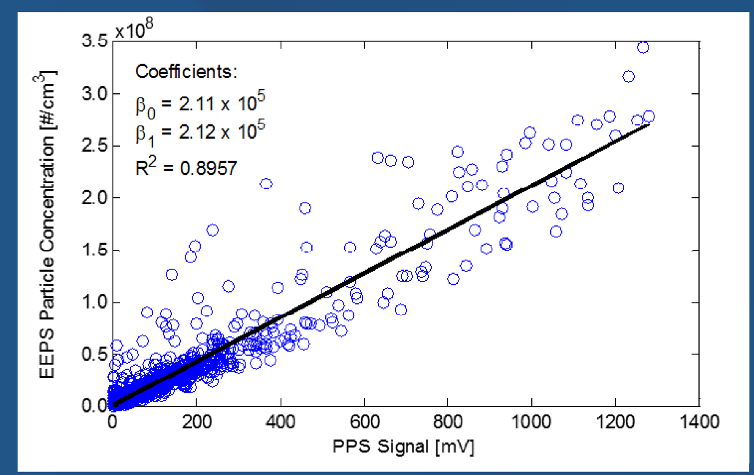
- Soot generator studies with AVL Particle Generator
  - => particle response as function of particle size mean diameter, particle concentration, particle volatility
  - => using SMPS, AVL MSS, electrical aerosol detector (diffusion-charging type instrument)
- Calculation of particle concentration ratio due to sample probe misalignment
- Particle loss characterization in sample probe, heated sample transfer lines and inside sensor
- Characterization of internal ion-trap to be applied as lower particle size cut-off (*e.g. PMP 23nm*)
- Characterization of supply air pressure and temperature effects onto dilution ratio in ejector pump

Parameter	Units	Value
N_A	1/mol	$6.022141793 \times 10^{23}$
d_m (for air)	M	3.667779×10^{-10}
T	K	573.15 (300°C)
P	N/m^2	101325
ρ_0	kg/m^3	1000
D_s	M	0.005
U_0	m/s	4.24

$$DR = \frac{Sample\ Outlet\ Flow\ [lpm]}{Sample\ Inlet\ Flow\ [lpm]}$$

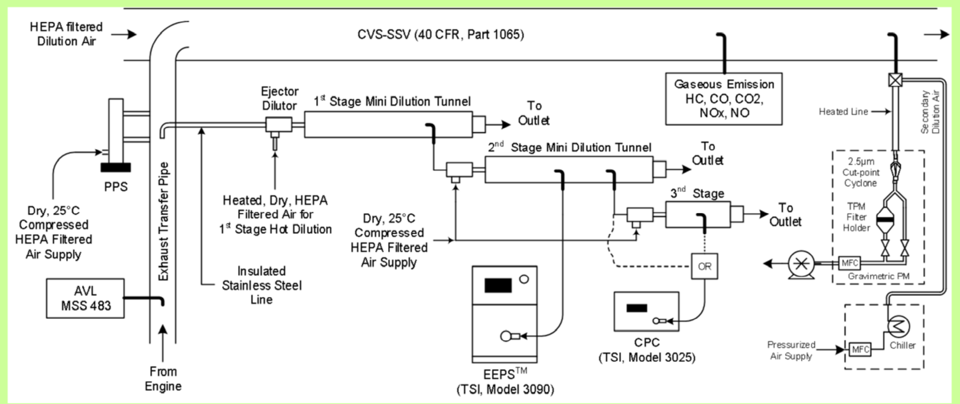


Developing Sensor Response Models



Controlled environment studies - engine dynamometer studies

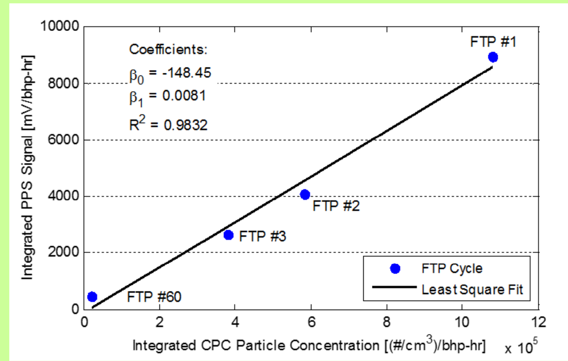
- Refining sensor response models over transient and steady-state engine operation
- Measurement verification against proven laboratory grade instruments and standards.



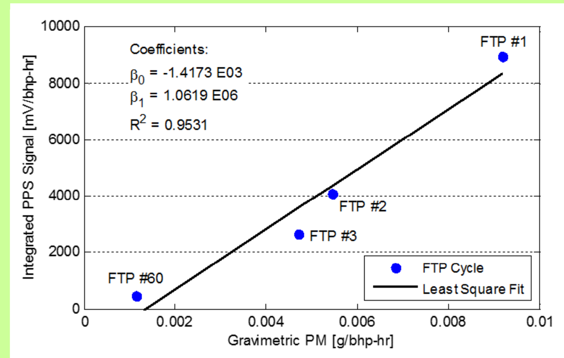
Filtration Efficiency Calculation

Test Run	PPS [mV/bhp-hr]	CPC [(#/cm³)/bhp-hr]	TPM [g/bhp-hr]
FTP #1	80.52 %	93.84 %	80.08 %
FTP #2	91.16 %	96.67 %	91.66 %
FTP #3	94.32 %	97.82 %	97.10 %
FTP #60	99.02 %	99.87 %	98.50 %

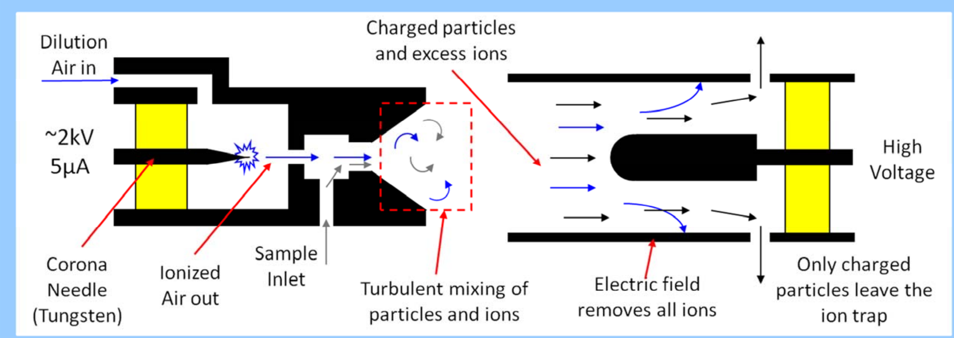
Integrated PPS vs. CPC Measurements



Integrated PPS vs. Gravimetric Measurement



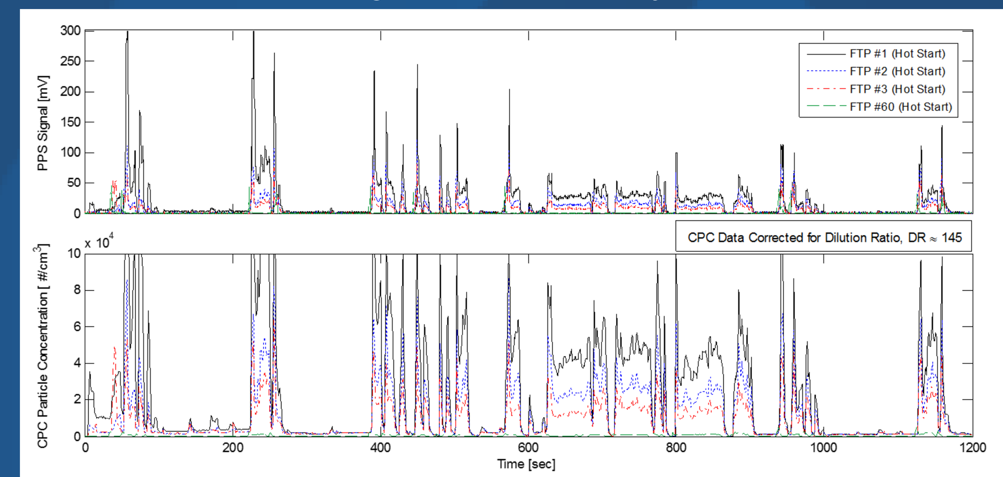
Diffusion-charging type sensor



Picture provided by Pegasor Oy

- PM detection based on diffusion charging and escaping current principle
- Flow through device => low maintenance
- Constant dilution air pressure leading to constant sample inlet flow => constant internal dilution ratio
- Sensor shows proportional response to particle surface area

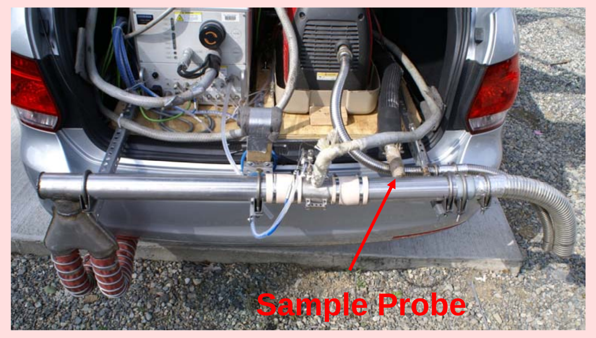
Cake-layer build-up of 'brand new' (i.e. non-degreened) DPF filter during consecutive FTP cycles

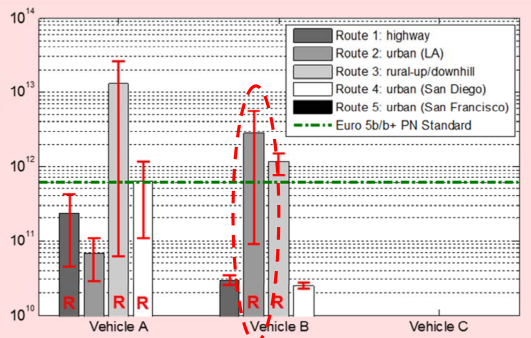


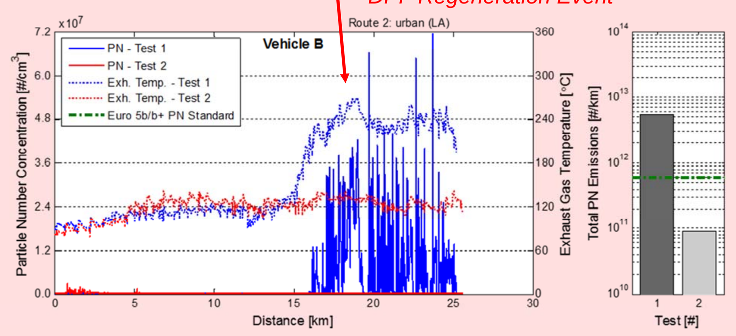
Analysis of:
- *Sensitivity*
- *Repeatability*
- *Accuracy*

Real-world, on-road studies

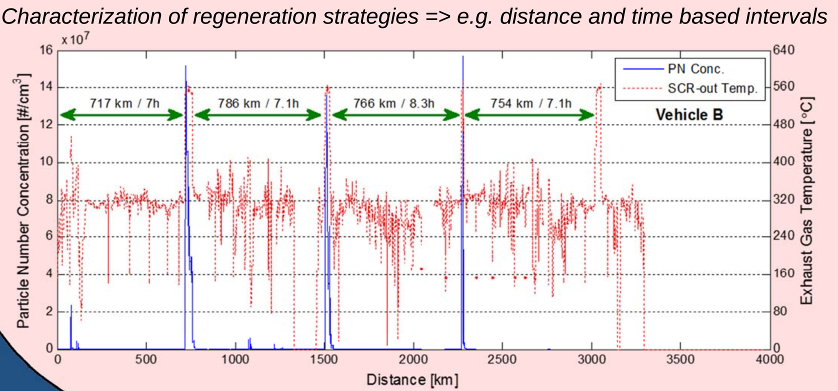
Light-duty vehicles application





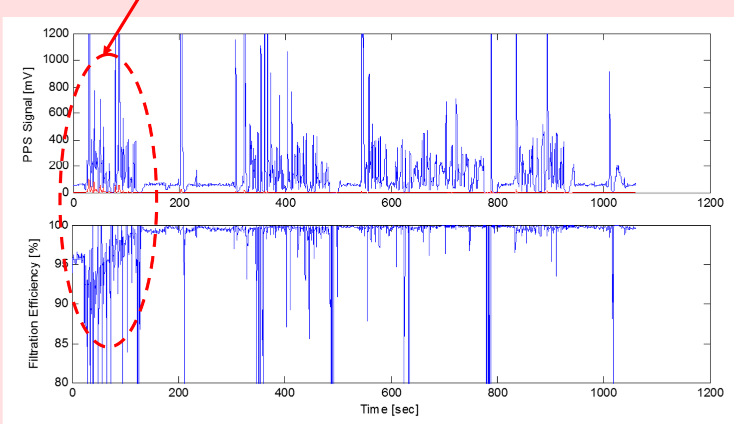


Characterization of regeneration strategies => e.g. distance and time based intervals

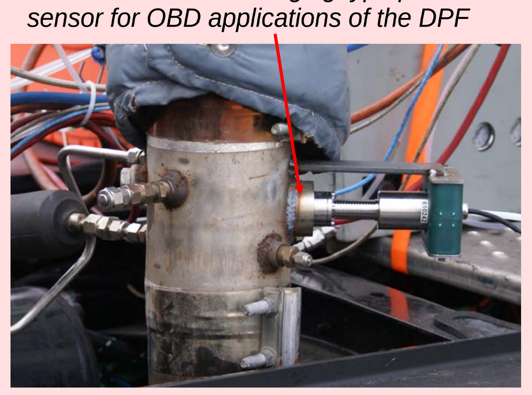


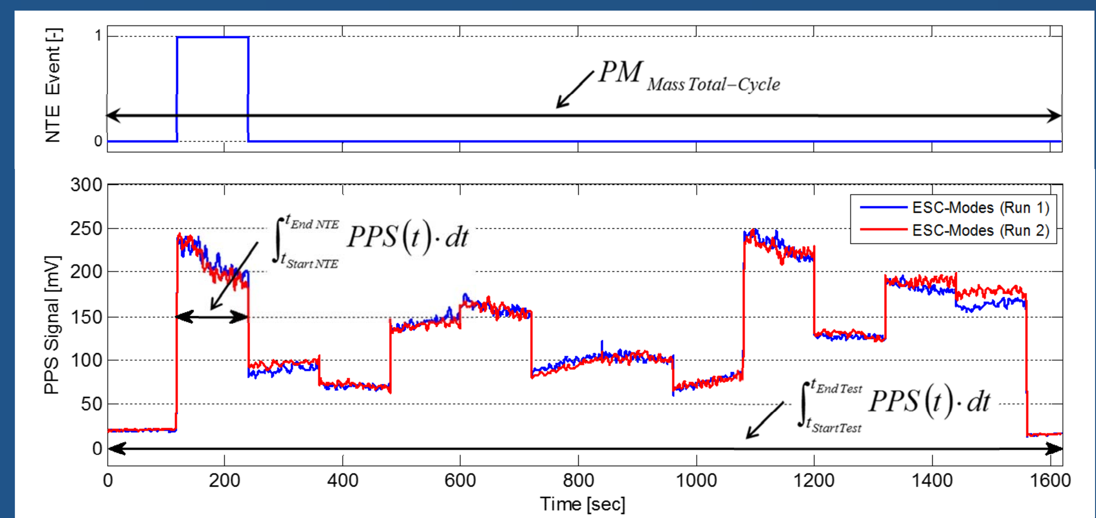
Heavy-duty vehicles application

Reduced DPF filtration efficiency at beginning of test cycle => Regeneration event during previous and start of this cycle.



Miniature diffusion-charging type particle sensor for OBD applications of the DPF





Evaluate Methods for In-Use PM Quantification

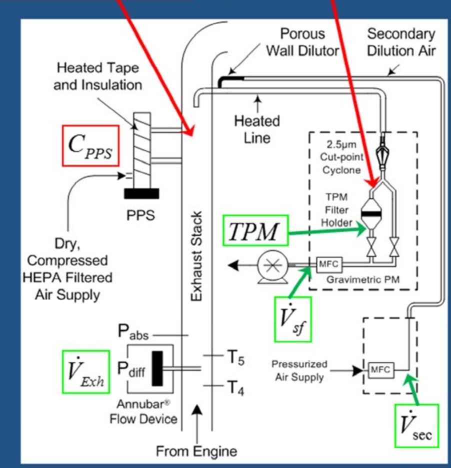
Calculation of PM mass [mg] during NTE event:

$$PM_{Ratio\ PPS} = \frac{\int_{Start\ NTE}^{End\ NTE} PPS(t)\cdot dt}{\int_{Start\ Test}^{End\ Test} PPS(t)\cdot dt}$$

$$PM_{Mass\ NTE} = PM_{Ratio\ PPS} \cdot PM_{Mass\ Total-Cycle}$$

$$C_{Exh} = C_{PPS} \cdot DR_{PPS}$$

$$C_{Filter} = C_{CVS} \cdot \frac{1}{DR_{Sec\ PM}}$$



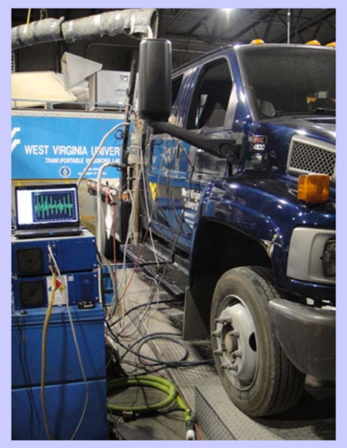
$\alpha_{Loss} = f(L, D, \dot{V}, \Delta T)$ (Not applied to presented results)

$$DR_{PPS} = 0.0053 \cdot [psi] + 1.3082$$

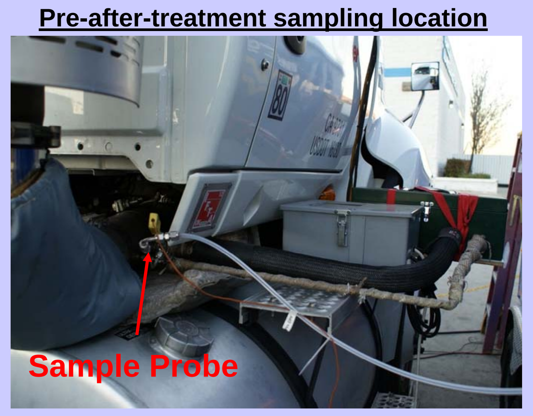
$$DR_{Sec\ PM} = \frac{\dot{V}_{tf}}{\dot{V}_{tf} - \dot{V}_{sec}}$$

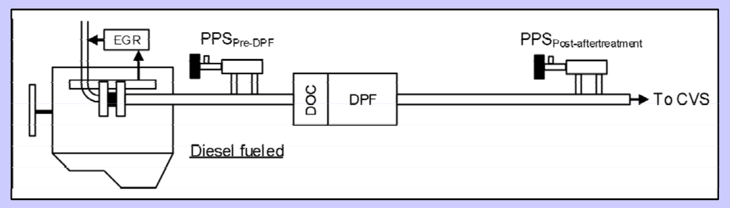
Semi-controlled environment studies - chassis dyno studies

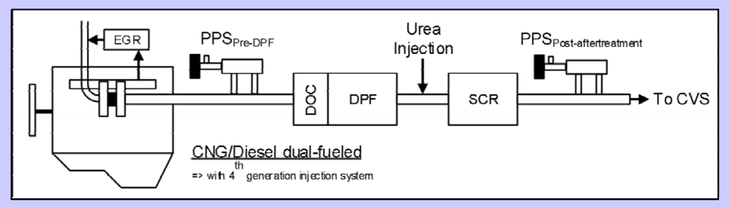
- Evaluation of particle response over wide range of engine and after-treatment technology, engine operating conditions, and fuels (i.e. Diesel, CNG, dual-fuel)



Pre-after-treatment sampling location







Post-after-treatment sampling location

19th ETH Conference on Combustion Generated Nanoparticles
June 28th - 1st, 2015, Zurich, Switzerland

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