West Virginia University

Real-Time DPF Filtration Efficiencies using In-Line Particulate Matter Sensors

CAFEE
Center for Alternative Fuels, Engines and Emissions

Marc C. Besch[1†], Arvind Thiruvengadam[1], Daniel K. Carder[1], Daniele Littera[1], Adewale Oshinuga[2], Randall Pasek[2], Juha Tikkanen[3] and Mridul Gautam[1]

[1] *West Virginia University, Department of Mechanical and Aerospace Engineering, Morgantown, West Virginia*

[2] *South Coast Air Quality Management District, Diamond Bay, California*

[3] *Pegasor Ltd., Tampere, Finland*

Introduction

Data presented within this poster is subpart to a major research project sponsored by South Coast AQMD "In-*Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy-Duty Engines*", which was carried out by West Virginia University during Fall 2011 and Spring 2013, using a transportable heavy-duty chassis dynamometer and a 40 CFR, Part 1065 compliant exhaust measurement system.

The primary objectives of the study presented herein are outlined as follows:

- **Evaluation of PM emissions from heavy-duty vehicles powered by Diesel or CNG/Diesel dual-fueled engines and equipped with advanced aftertreatment technology using chassis dynamometer**
  - Characterization of particle size spectrums and number concentrations post aftertreatment systems
  - Particle number concentration with regard to proposed Particulate Number (PN) limit for Euro VI legislation
  - Quantify particle number concentrations at engine out location using in-line particle sensor
- **Characterize real-time DPF filtration efficiencies using in-line particle sensor up/downstream DPF**
  - Effect of regeneration events on DPF filtration efficiency
  - Restoring rate of high filtration efficiency after regeneration event => "soot cake layer" build up
- **Evaluation of In-line, Real-time Particle Sensor (Pegasor Particle Sensor)**
  - Establishing mass reference for aerosol in real-time
  - Study influence of different engine/aftertreatment technologies on sensor response

Test Vehicles and Cycles

Vehicle Class	Test Cycles
Goods Movement Truck	UDDS Drayage Cycles (Regional, Local and Neardock driving)
Refuse Truck	UDDS CBD Cycle OCTA Cycle
Transit Bus	UDDS AQMD Refuse Truck Cycle AQMD Compaction Cycle

UDDS - Urban Dynamometer Driving Schedule
CBD - Central Business District Cycle
OCTA - Orange County Transit Authority Cycle

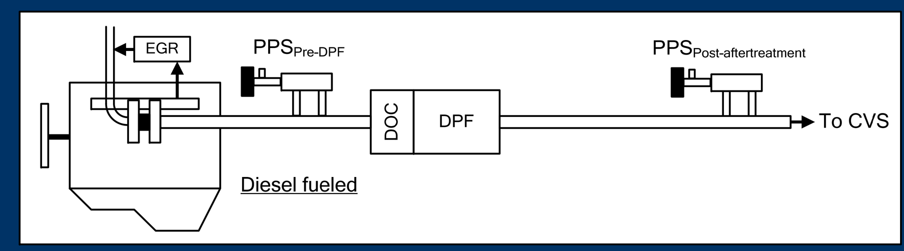
AQMD Refuse Truck Cycle
=> Modified William H. Martin Refuse Truck Cycle

Drayage Cycles
=> Representing typical driving conditions experienced by goods movement operation in and around the ports of Los Angeles (by TIAX LLC)

Vehicle Technology

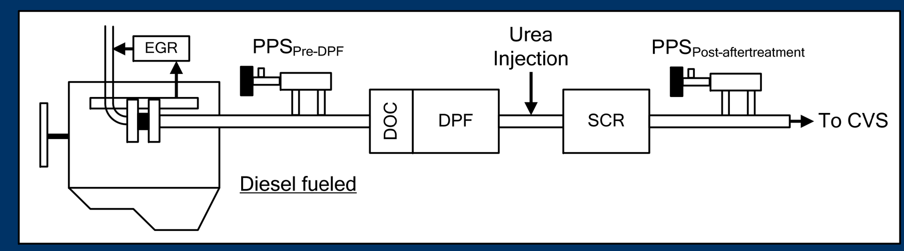
Diesel fueled at 1.2 g/bhp-hr NO_x

- DOC/DPF after-treatment system only
- EGR



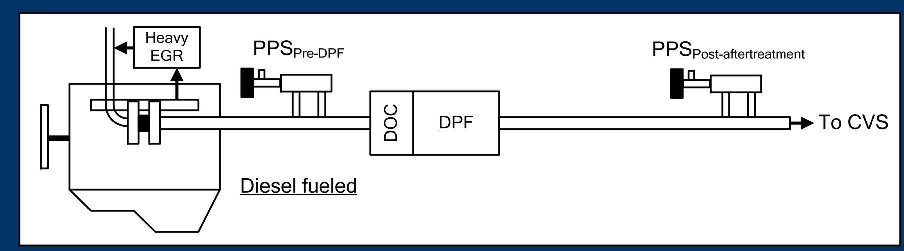
Diesel fueled at ≤ 0.2 g/bhp-hr NO_x

- DOC/DPF after-treatment system
- Liquid urea-SCR after-treatment system
- EGR



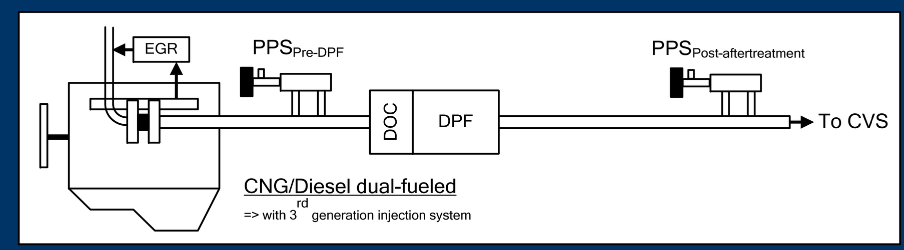
Diesel fueled at > 0.2 g/bhp-hr NO_x

- DOC/DPF after-treatment system only
- Heavy-EGR strategy for NO_x reduction



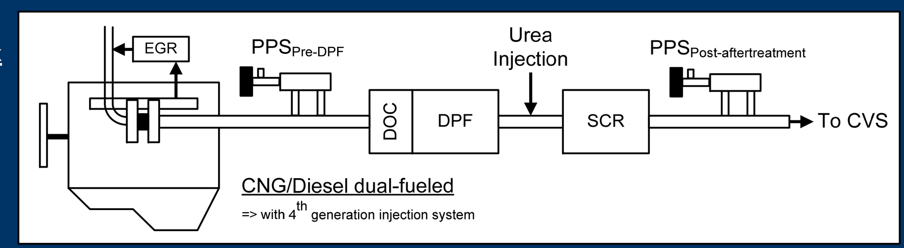
CNG/Diesel dual-fueled at 0.8 g/bhp-hr NO_x

- HPDI system of 3rd generation
- DOC/DPF after-treatment system only
- EGR

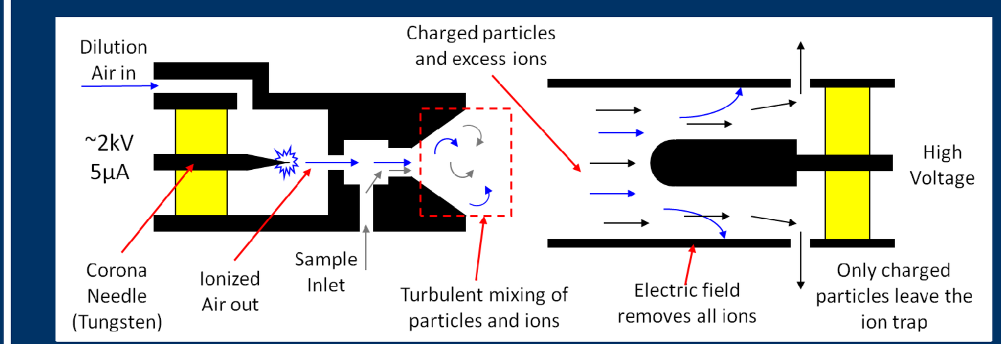


CNG/Diesel dual-fueled at ≤ 0.2 g/bhp-hr NO_x

- HPDI system of 4th generation
- DOC/DPF after-treatment system
- Liquid urea-SCR after-treatment system
- EGR



Instrumentation - Real-Time Particle 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

Pre Aftertreatment Sampling Location

- Sample extraction via 3ft heated line (@200°C)
- Internal DR ≈ 2.9 @ 22psi dil. pressure
- Sensor heated to 200°C

Post Aftertreatment Sampling Location

- Directly mounted to exhaust stack
- Internal DR ≈ 3.06 @ 22psi dil. pressure
- Sensor heated to 200°C

Results and Discussion

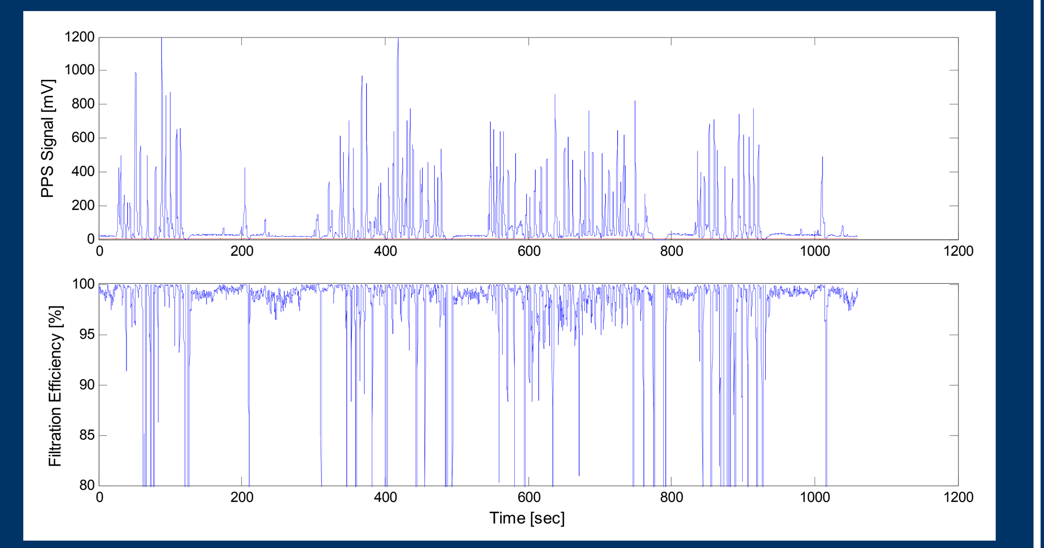
Diesel fueled at ≤ 0.2 g/bhp-hr NO_x (SCR/DPF) over UDDS

- Raw PPS Signal filtered with Savitzky-Golay Filter (Order: 5, Window: 21)
- Sensor time alignment => transport delay through aftertreatment system

Filtration efficiency calculation:

$$\eta_{DPF} = 1 - \frac{PPS_{post\ aftertreatment}}{PPS_{pre\ DPF}}$$

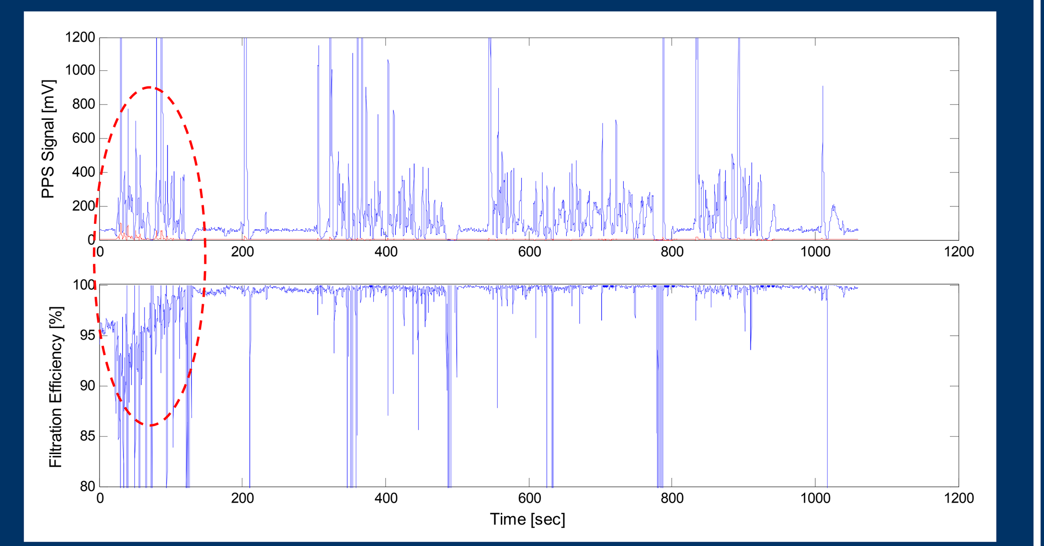
Axle-Work-specific PN [#/kW-hr]	1.12 E+13
Distance-specific PN [#/km]	1.89 E+13
DPF Filtration Efficiency [%]	99.61



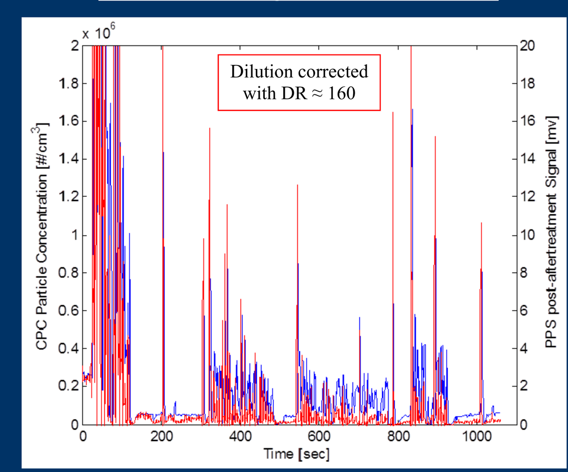
Diesel fueled at 1.2 g/bhp-hr NO_x (DPF only) over UDDS

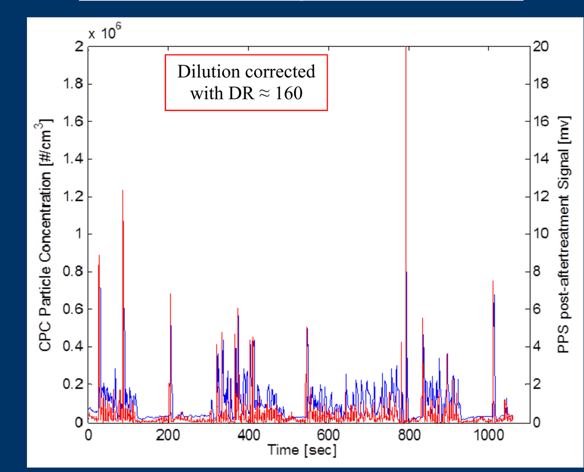
- Reduced DPF filtration efficiency at beginning of test cycle => Regeneration event during previous and start of above plotted test cycle
- 3 fold increase in PN during cycle with regeneration event
- Total engine-out PN levels increase by ~25%

	w/ Regen.	w/o Regen.
Axle-Work-specific PN [#/kW-hr]	6.22 E+13	2.16 E+13
Distance-specific PN [#/km]	9.92 E+13	3.44 E+13
DPF Filtration Efficiency [%]	99.0	99.59



With DPF Regeneration Event / **Without DPF Regeneration Event**





Conclusion and Summary

- Real-time DPF filtration efficiency calculation via DPF up/downstream particulate matter measurements using in-line particle sensor (Pegasor Particle Sensor).
- Total particle number concentrations (CPC) over UDDS for all vehicle/aftertreatment configurations between 10^{12} to 10^{13} [#/km].
- Total particle number concentrations (CPC) increase 3 fold during test cycle with regeneration event.
- DPF filtration efficiencies over UDDS for all vehicle/aftertreatment configurations on average at or above 99%.
- Momentarily reduction in DPF filtration efficiency during and immediately after regeneration events due to soot cake layer reduction => dropping to 90%

Sponsors: AQMD, California Air Resources Board, pegasor

17th ETH Conference on Combustion Generated Nanoparticles
June 23rd - 26th, 2013, Zurich, Switzerland

† For more information please contact: Marc C. Besch
Center for Alternative Fuels, Engines and Emissions (CAFEE)
email: marc.besch@mail.wvu.edu
West Virginia University
Morgantown, WV 26506
voice: (304) 906 - 7897