REAL-WORLD ON-ROAD PARTICULATE MATTER EMISSIONS FROM LATEST TECHNOLOGY HEAVY-DUTY VEHICLES USING A MOBILE CVS LABORATORY

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INTRODUCTION

- Real-world emissions from heavy-duty vehicles are of importance
  - Operation of SCR (identifying operations leading to higher NOx emissions)
  - DPF filtration efficiencies (Operations that could lead to higher solid particle emissions)
- In addition to in-use conformity testing using PEMS instrumentation, the use of a transportable, laboratory-grade CVS system offers better accuracy and versatility in integrating measurement instrumentation
  - Regulated pollutants(laboratory grade and PEMS)
  - Unregulated pollutants (FTIR)
  - PM speciation (EEPS, PMP sampling, soot sensor, etc.)
- European RDE proposal also voices the need for monitoring vehicle emissions beyond just certification cycles, in particular urban operation.

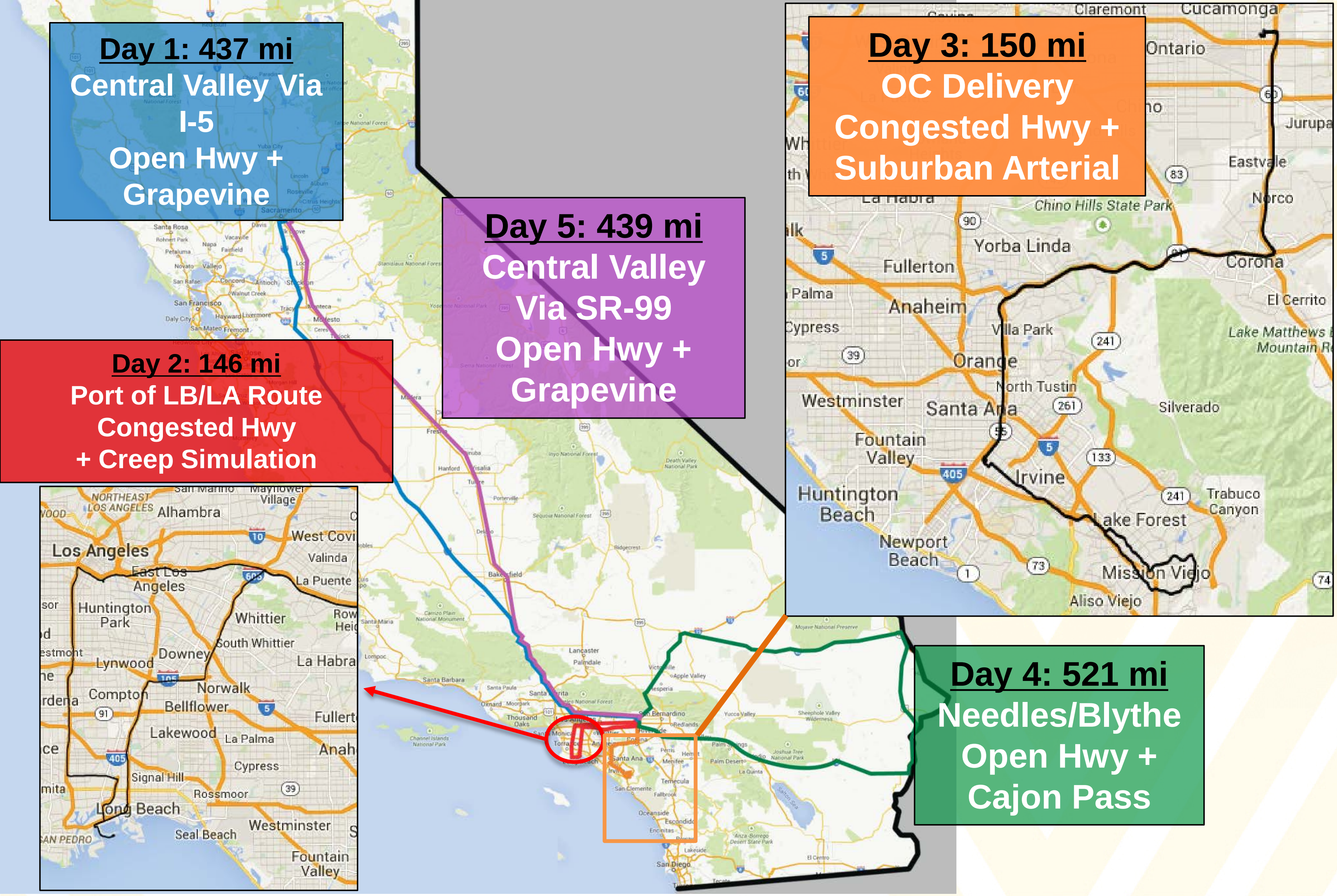
Day 1: 437 mi
Central Valley Via I-5
Open Hwy + Grapevine

Day 2: 146 mi
Port of LB/LA Route
Congested Hwy + Creep Simulation

Day 3: 150 mi
OC Delivery
Congested Hwy + Suburban Arterial

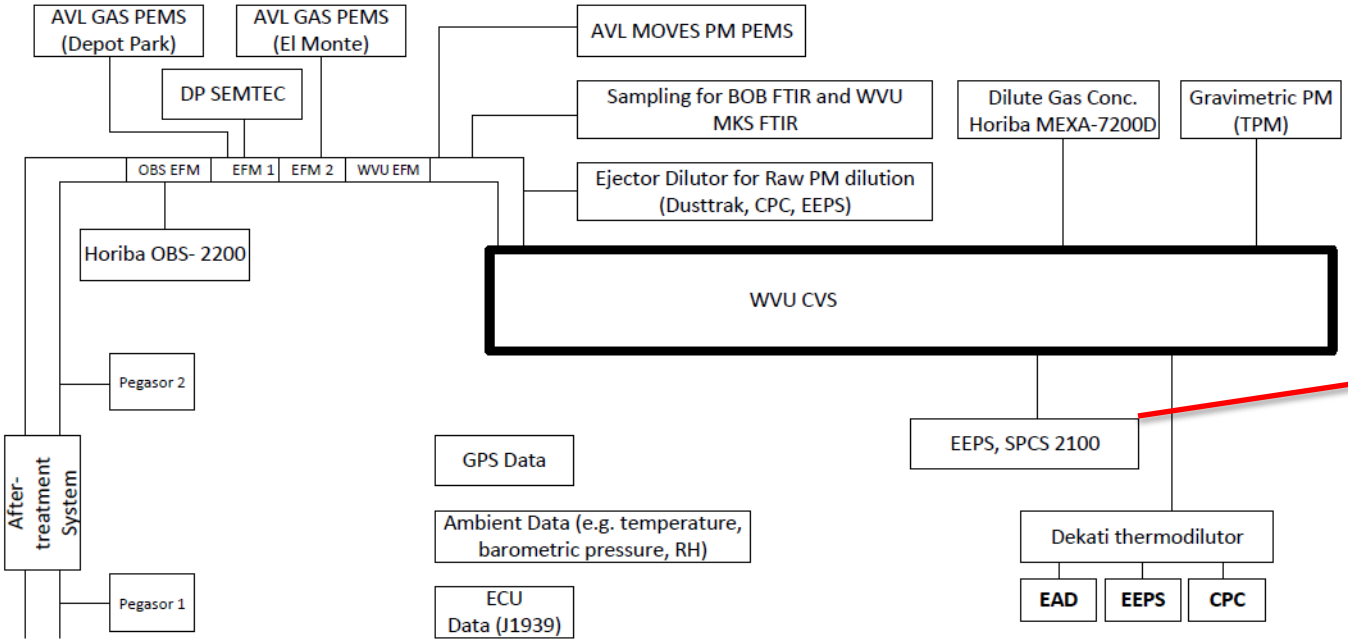
Day 4: 521 mi
Needles/Blythe
Open Hwy + Cajon Pass

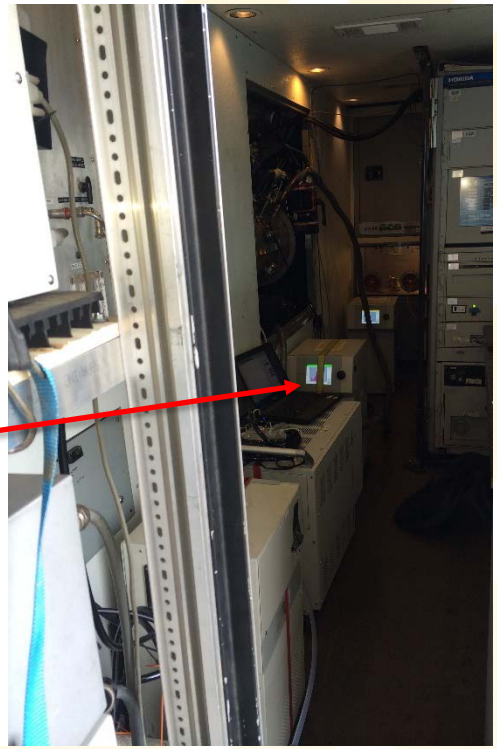
Day 5: 439 mi
Central Valley Via SR-99
Open Hwy + Grapevine



Sacramento
Stockton
San Francisco
Modesto
Fresno
Bakersfield
Santa Barbara
Lancaster
Palmdale
San Bernardino
Palm Springs
San Diego
Alhambra
Los Angeles
East Los Angeles
Huntington Park
Whittier
Downey
Lynwood
Compton
Norwalk
Bellflower
Lakewood
La Palma
Cypress
Signal Hill
Rossmoor
Long Beach
Seal Beach
Westminster
Fountain Valley
La Habra
La Puente
West Covina
Ontario
Cucamonga
Claremont
Jurupa
Eastvale
Norco
Chino Hills State Park
Yorba Linda
Corona
Fullerton
Anaheim
Villa Park
Orange
El Cerrito
North Tustin
Santa Ana
Silverado
Irvine
Huntington Beach
Newport Beach
Lake Forest
Trabuco Canyon
Mission Viejo
Aliso Viejo

SAMPLING SETUP





- Three dilution setups were used
  - Mini-Dilution Setup: Ejector-type dilution of raw exhaust (HEPA filtered dry pressurized air at 25 DegC)
  - CVS dilution with HEPA filtered ambient air
  - Thermodilution using rotating disk dilutor and TSI Thermodilution (Model 379020A) and Conditioning system (PMP compliant-Model 379030)

TEST VEHICLES

Vehicle	Engine Model	After Treatment System
Vehicle 1 (MY 2008)	Cummins ISX 525	DPF only
Vehicle 2 (MY 2013)	Cummins ISX 15/450	DPF and SCR
Vehicle 3 (MY 2013)	Cummins ISX 12G (Natural gas)	Three-way catalyst
Vehicle 4 (MY 2014)	Detroit Diesel DDC15	DPF, SCR and AMOX

- *Vehicle 5 (Volvo D13 with DPF and SCR) and Vehicle 6 (Navistar N13 with DPF and SCR) to be tested.*

KEY QUESTIONS OR HYPOTHESES

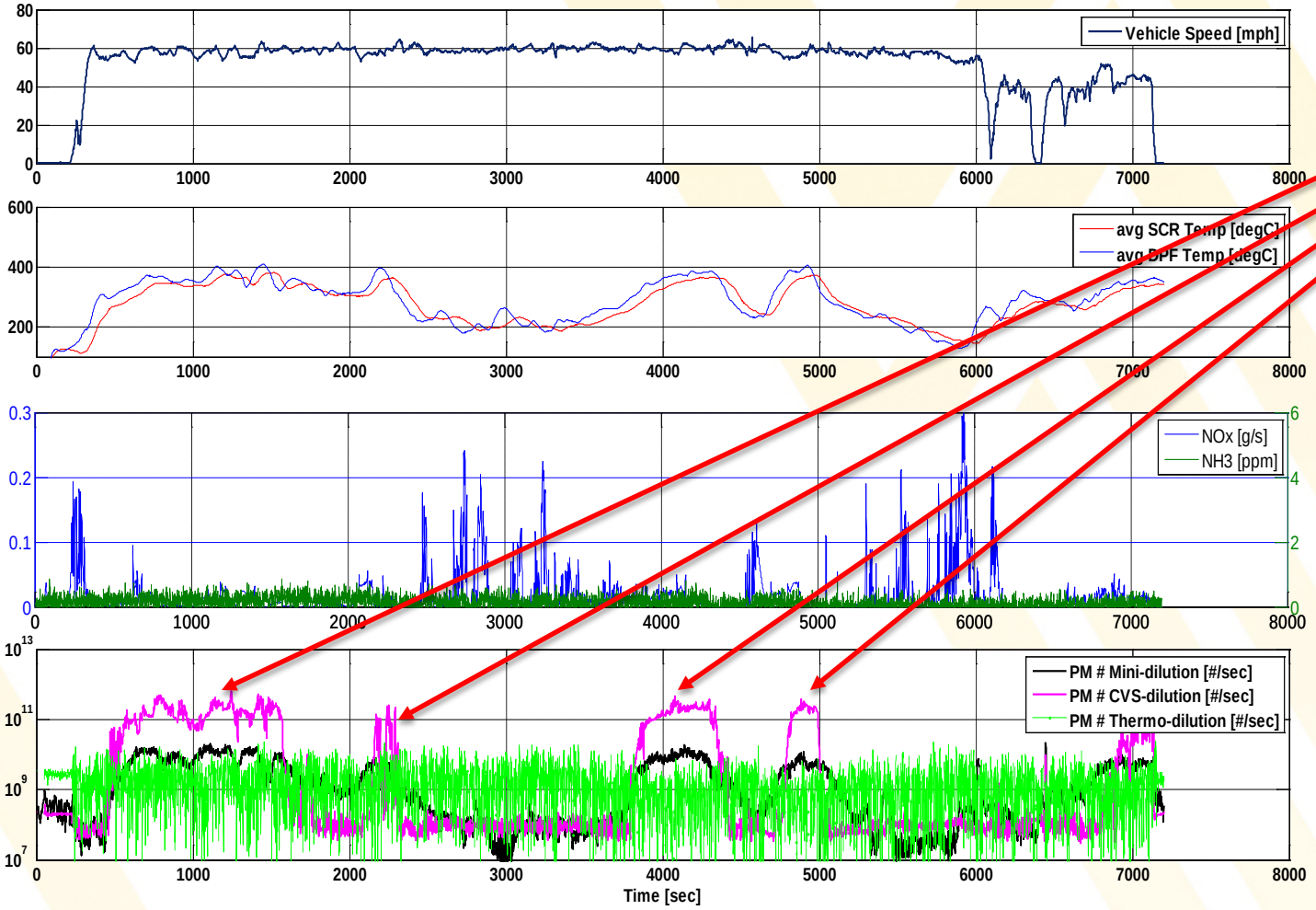
Question 1: Does the activity of SCR result in any new particle formation?

Question 2: How effective are DPFs during real-world operation?

Hypothesis 1: Idle and low load operation of natural gas engines produces higher PM emissions. Such PM emissions are dominated by lubrication oil derivatives.

Hypothesis 2: No significant differences in PM emissions are observed between different engine manufacturer platforms.

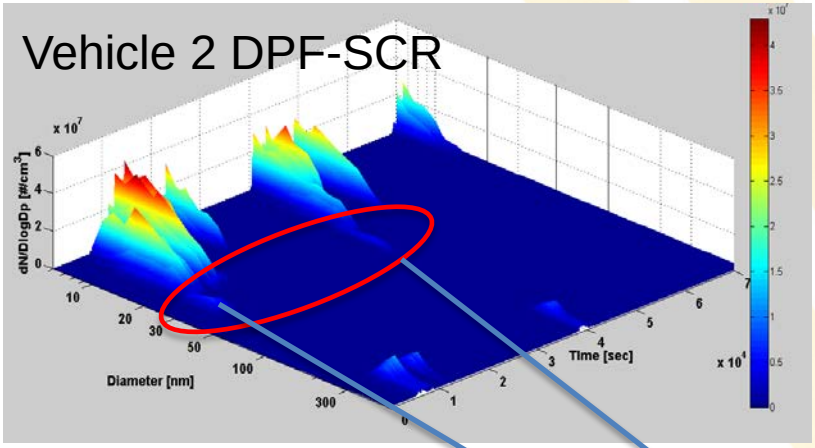
RESULTS: QUESTION 1
SCR ACTIVITY AND PARTICLE FORMATION

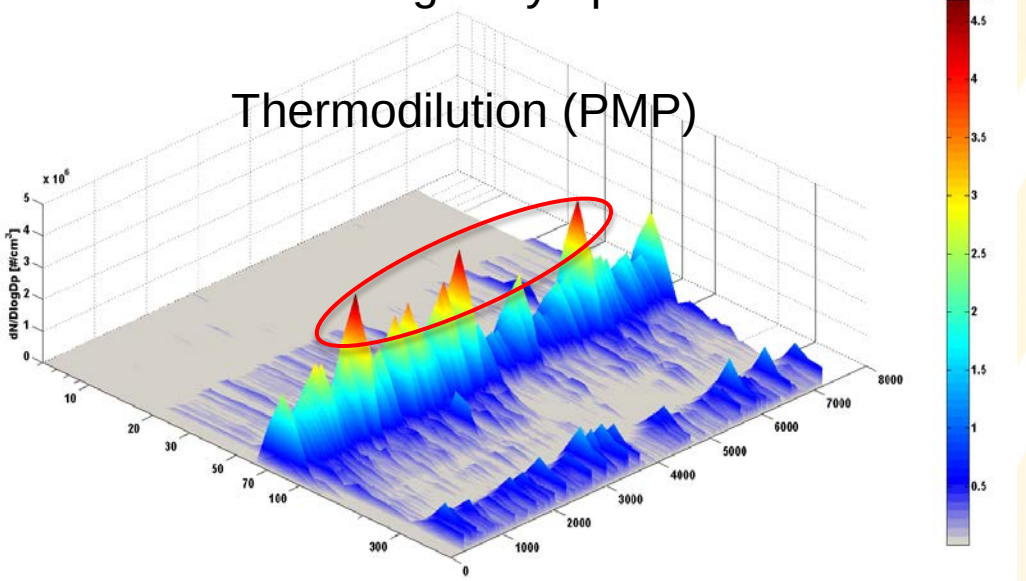


Periodic SCR activity and increased PN count

Observed particles are believed to be liquid in nature and magnitude is lowered upon heat treatment of sample

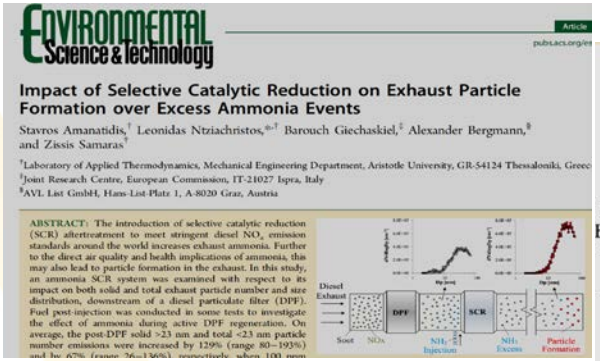
Results derived from extended highway operation





Accumulation mode particles coinciding with SCR activity

- **Further questions: Ammonium nitrate? Ammonium sulfate or ammonium chloride????????**
- **Aggressive urea dosing could increase the particle count**



Environmental Science & Technology

Article

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Impact of Selective Catalytic Reduction on Exhaust Particle Formation over Excess Ammonia Events

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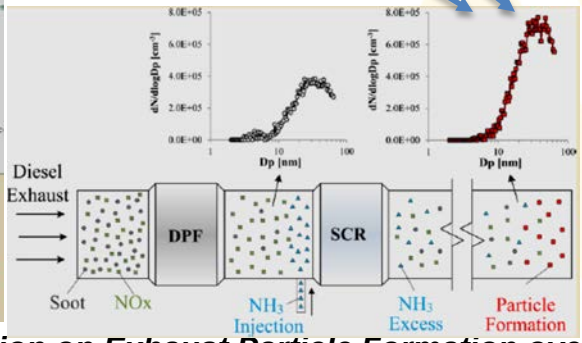
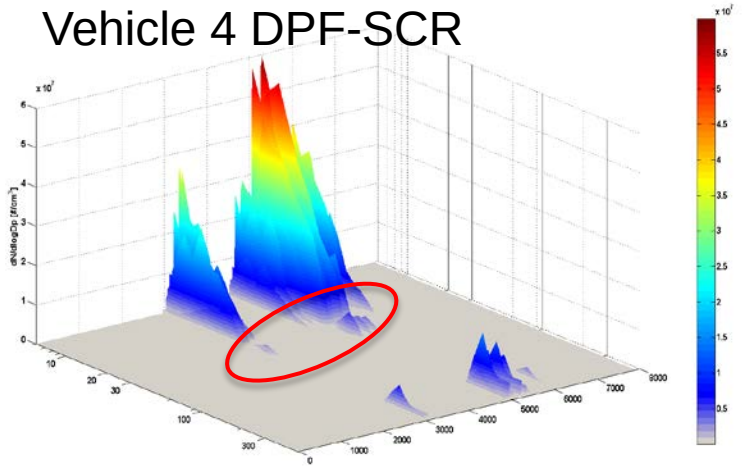
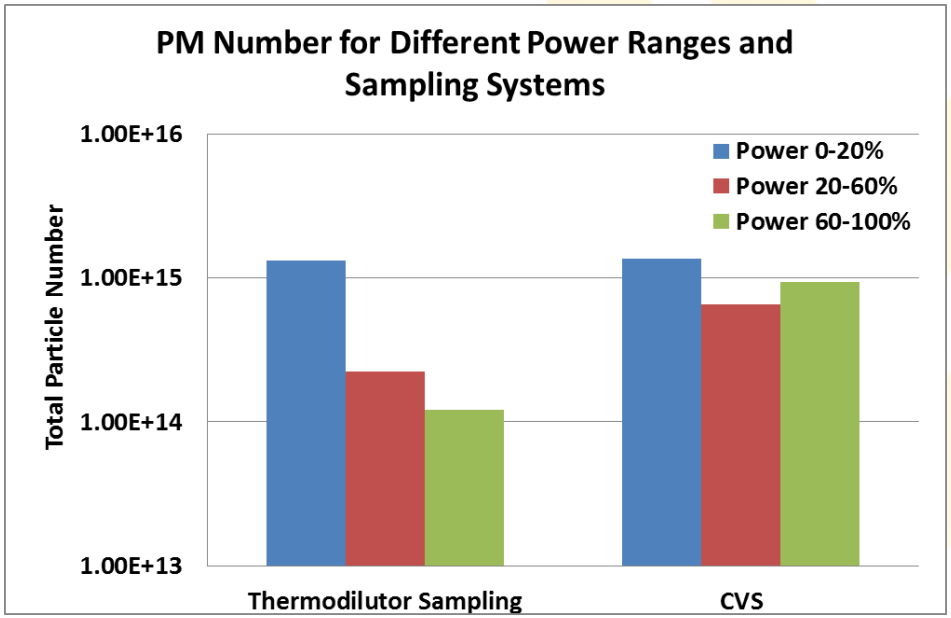
ABSTRACT: The introduction of selective catalytic reduction (SCR) aftertreatment to meet stringent diesel NO_x emission standards around the world increases exhaust ammonia. Further to the direct air quality and health implications of ammonia, this may also lead to particle formation in the exhaust. In this study, an ammonia SCR system was examined with respect to its impact on both solid and total exhaust particle number and size distribution, downstream of a diesel particulate filter (DPF). Fuel post-injection was conducted in some tests to investigate the effect of ammonia during active DPF regeneration. On average, the post-DPF solid >23 nm and total >23 nm particle number emissions were increased by 129% (range 80−193%) and by 67% (range 26−136%), respectively, when 100 ppm

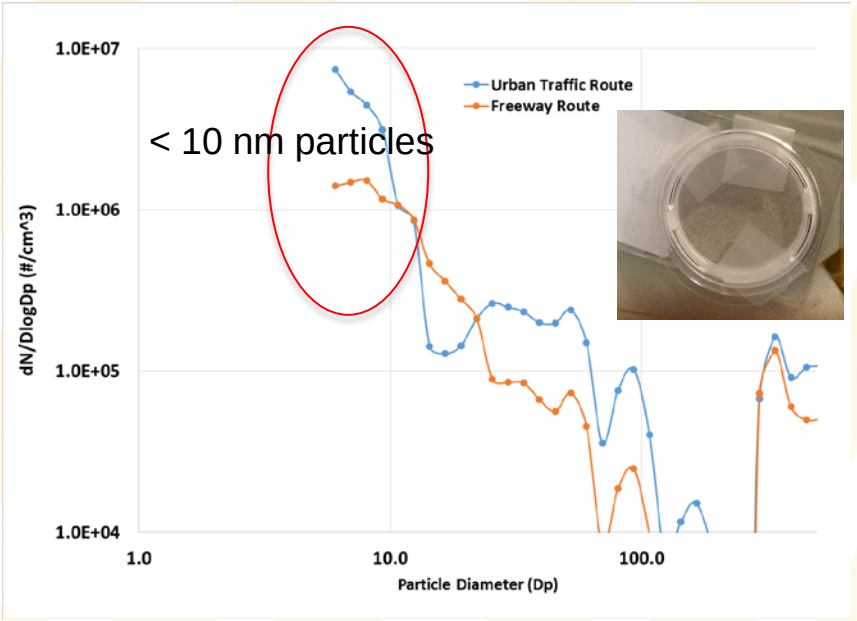




Impact of Selective Catalytic Reduction on Exhaust Particle Formation over Excess Ammonia Events, Environ. Science and Tech, 2014, 48, 11527−11534

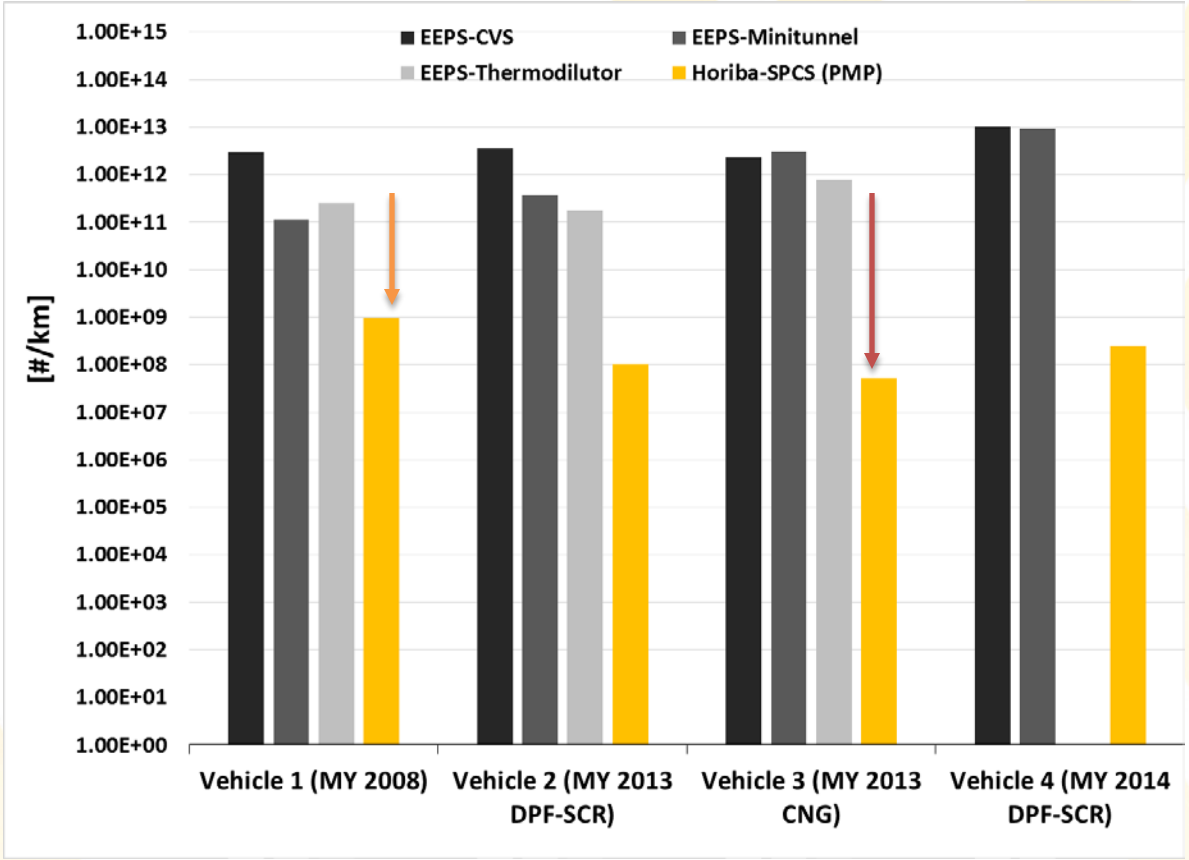
RESULTS: HYPOTHESIS 1
NATURAL GAS ENGINE PM VS ENGINE LOAD





- For measurements from the CVS no significant differences are observed in PM emissions between different power levels
- In the case of thermodilution of sample
  - Close to an order of magnitude higher PN count for power levels between idle and 20% load in comparison to higher load operation
- Previous studies on chassis dynamometer have indicated possible inorganic nucleation mode particles derived from lube oil.
- Presence of nucleation mode particles after evaporator stage of thermodilutor indicates the possible presence of solid particles (lube oil ash, re-nucleated lube oil additives)

RESULTS: HYPOTHESIS 2
DIFFERENCES IN PM EMISSIONS BETWEEN ENGINE PLATFORMS

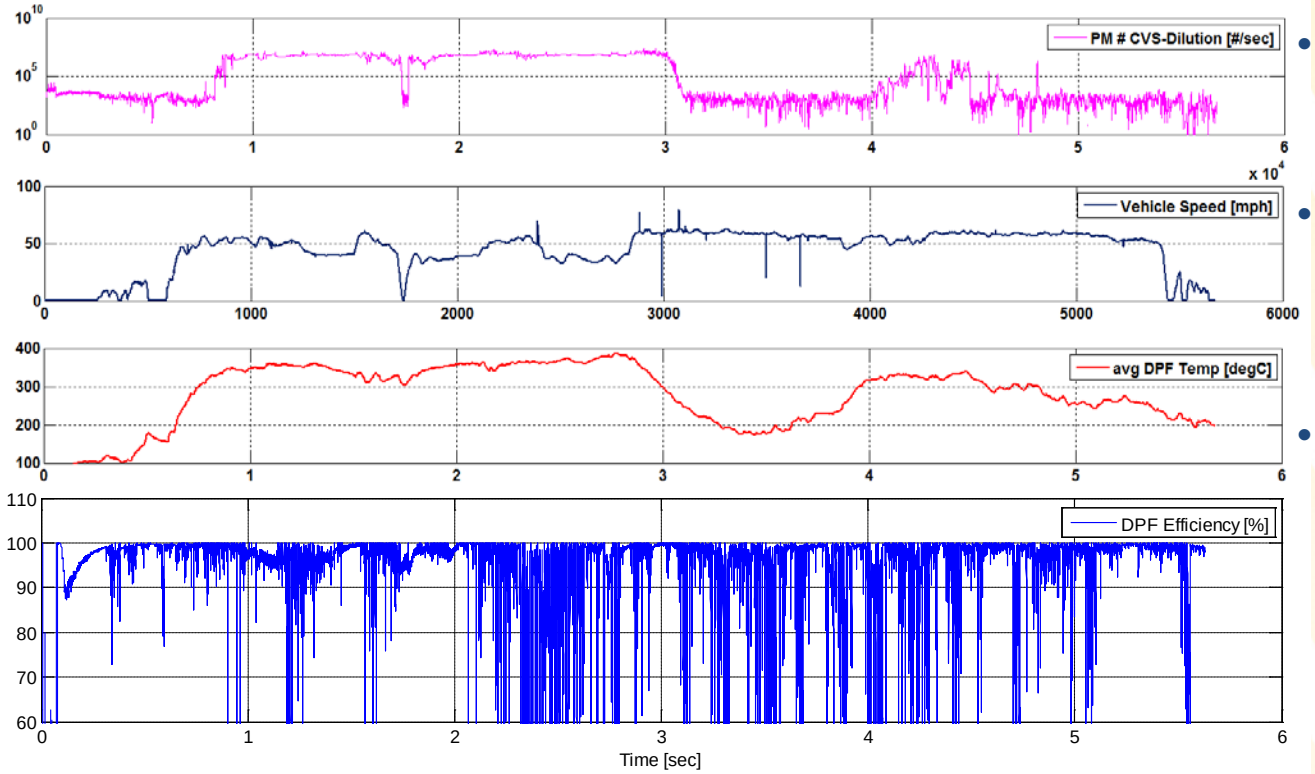


Above chart represents PN count for hill climb route

- Distance-specific PN count are well below the to EU-PN regulation of 6 X 10^{11} #/km
- Higher PN count with thermodilutor sampling with a 2.5 nm cut-point CPC, indicates particles below 23 nm exists even after thermal conditioning
- Differences in after-treatment design and urea dosing strategy between vehicles 2 and 4 do not seem to influence the PN count significantly
- In the case of natural gas engines the PMP measurement might be ignoring the inorganic particles below 23 nm

Vehicle 2 was equipped with a conventional DPF and SCR while Vehicle 4 was equipped with an integrated DPF and SCR design with an Ammonia Oxi. Catalyst

RESULTS: QUESTION 2
REAL WORLD DPF EFFICIENCY



- Close to 100% filtration efficiency during all operating conditions
- Above chart shows filtration efficiency for hill climb route with maximum gravimetric filter loading
- No regeneration events observed during the 1700 mi test campaign on each vehicle

ON A SEPARATE NOTE

Need of the hour: Robust OBD strategy to detect DPF failures (tailpipe sensors????)

DPF failures caused as a cascading effect originating from a engine durability issues- EGR related issues invariably result in DPF failures undetected by engine

CONCLUSIONS

1. SCR activity results in particles both in nucleation (e.g. sulfates) and accumulation mode
2. Composition and the environmental impact (if any) from these accumulation mode particles is worth investigating
3. Solid particles in the nucleation mode are observed in exhaust of natural gas vehicles
    a) Data from this study suggests that lubrication oil contribution is prevalent even in engines with less miles
    b) Engine component ageing could potentially increase the PN count from natural gas engines
4. No significant differences in PM emissions (both mass and number) were observed between different engine manufacturers
    1. It would be interesting to observe the impact of optional regulation such as ARB 0.02 g/bhp-hr Nox standard on PM emissions
5. OBD related development of PM sensors or fault detection algorithms are the need of the hour to monitor DPF efficiency

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