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EVALUATION OF THE EUROPEAN PMP METHODOLOGIES USING CHASSIS DYNAMOMETER AND ON-ROAD TESTING OF HEAVY-DUTY VEHICLES

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ABSTRACT

As regulatory limits in California and the US for 2007 heavy-duty diesel engines introduce dramatic reductions in PM emissions, there is considerable interest in new emission metrology that can more accurately measure low PM levels. One such metrology, particle number measurement, has been extensively investigated in Europe as part of Europe's Particle Measurement Program (PMP) for light-duty diesel vehicles. This program has put forth a new methodology, including instrument specifications and sampling protocols, for "solid" particle number measurements. While counting only solid particles may not be indicative of all of diesel PM health effects, this still represents a significant advancement as it is currently the only methodology with low enough detection limits to produce precise measurements of DPF equipped engines. The specific objective of this study was to critically evaluate the proposed PMP method for determining "solid" particle number emissions from heavy-duty vehicles in the laboratory and during over-the-road driving. This study is complementary to the investigation by CARB involving the PMP Golden Vehicle and presented last year.

For this program, testing was conducted on the chassis dynamometer at the CARB heavy-duty vehicle emissions laboratory in Los Angeles and over the road with the CE-CERT mobile emissions laboratory (MEL). Testing over the road is a novel idea uniquely enabled by the MEL and where the interest rests on the investigating the plausibility of "real-world," yet rigorous emission measurements with the PMP method. One or two PMP compliant dilution systems for measuring solid particle number were tested and compared directly with filter-based PM measurements on two heavy-duty trucks equipped with a DPF. A full suite of other particle measurements and instruments were also used in conjunction with this testing including an EEPS, a Cambustion DMS, CPCs with cut-off size ranges from 3 to 20 nm, a Dekati DMM, and a TSI Dustrak. The test cycles included a 50 mph cruise, UDDS, idle, and some European driving schedules.

On-road testing showed that gravimetric PM filter mass measurements were near detection limits for most of driving cycles, which makes it desirable to explore the new PM measurement

protocol. The CPC particle number count levels follow a trend that is consistent with the size cuts of the respective instruments, with the particle counts for the 3760s (~11 nm) and the 3790 (20 nm) being considerably less than those of the 3022 (7 nm) and the 3025As (3 nm), suggesting the presence of sub-20nm "solid" particles making it through the PMP sampling train. The 3022 CPC, which was connected to the primary tunnel as opposed to below the PMP system, also showed higher counts than the other CPCs below the PMP system when volatile nucleation particles formed as shown in Figure 1. The particle number measurements using PMP method showed a lower coefficient of variation than the PM filter mass measurements as shown in Figure 2. One key advantage of particle number measurements is better repeatability at low mass levels. The results of this study including on-road and laboratory testing on chassis dynamometer will be presented.

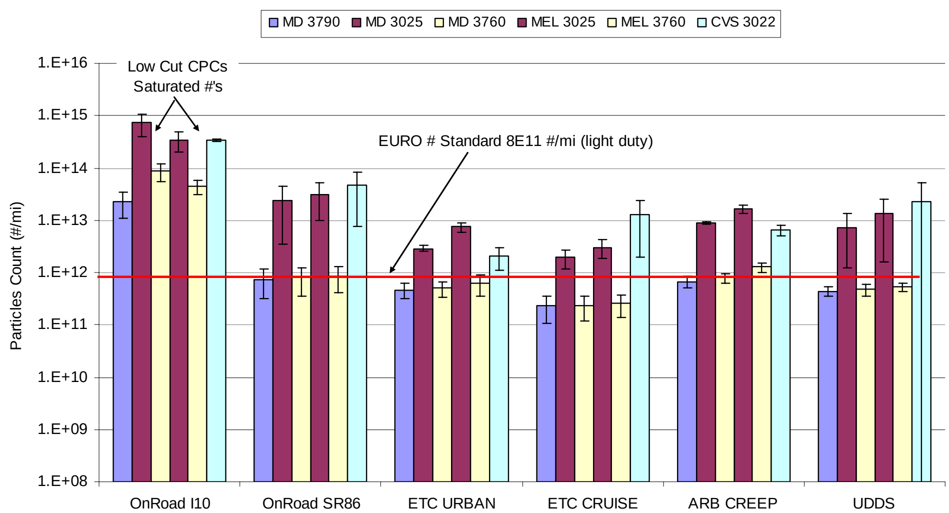

Figure 1. Particle number rate (#/mile) on driving cycles for on-road testing

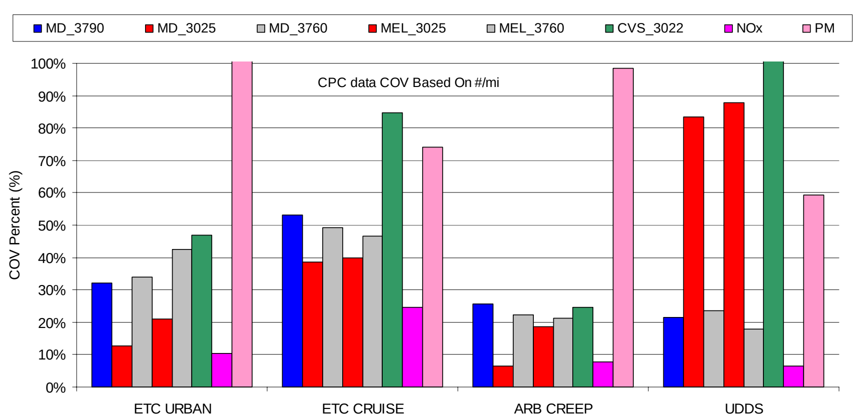

Figure 2. Coefficient of variation for all CPCs and PM mass on driving cycles for on-road testing

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  - Dr. Andreas Mayer of Technik Thermischer Maschinen (TTM).
  - for their assistance in developing the test plan procedures, in carrying out the experiments, and in analysis of the data.
  - Mr. Donald Pacocha, for his contribution in setting up and executing this field project, the data collection and quality control.
  - Joint Research Center (JRC) of the European Commission

Overview

- Background
- Objectives
- Experimental setup
- Results
  - Integrated data
  - Real time data
- Conclusion

Background

- Current gravimetric method have increasing difficulty quantifying post-DPF PM mass emissions accurately.
  - Background contribution
  - Insensitive to DPF fill state

- Euro 5/6 standard includes measurement of solid particles (>23nm) as an additional new metric of particles emitted from light-duty diesel vehicle.

Objectives

- Critical evaluation of the proposed European PMP method for determining particle emissions from heavy-duty diesels and its potential in California for PM measurement and in-use screening.

- Particle mass vs particle number.

Lab testing (at CARB MTA lab)

UCR/CE-CERT’s Mobile Emission Lab (MEL) for On-Road Testing

Diluted Exhaust: Temperature, Absolute Pressure, Throat ΔP, Flow.

GPS: Pat, Long, Elevation, # Satellite Precision.

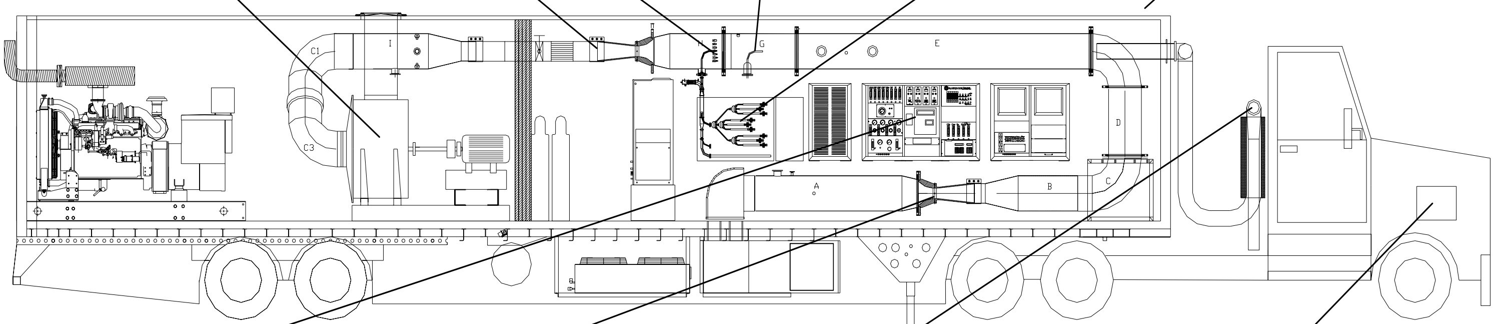
CVS Turbine: 1000-4000 SCFM, Variable Dilution.

Secondary Probe.

Gas Sample Probe.

Secondary Dilution System* PM (size, Mass).

Drivers Aid.



Gas Measurements: CO_2 %, O_2 %, CO ppm, NO_x ppm, THC ppm, CH_4 ppm.

Other Sensor: Dew Point, Ambient Temperature, Control room temperature, Ambient Baro, Trailer Speed (rpm), CVS Inlet Temperature.

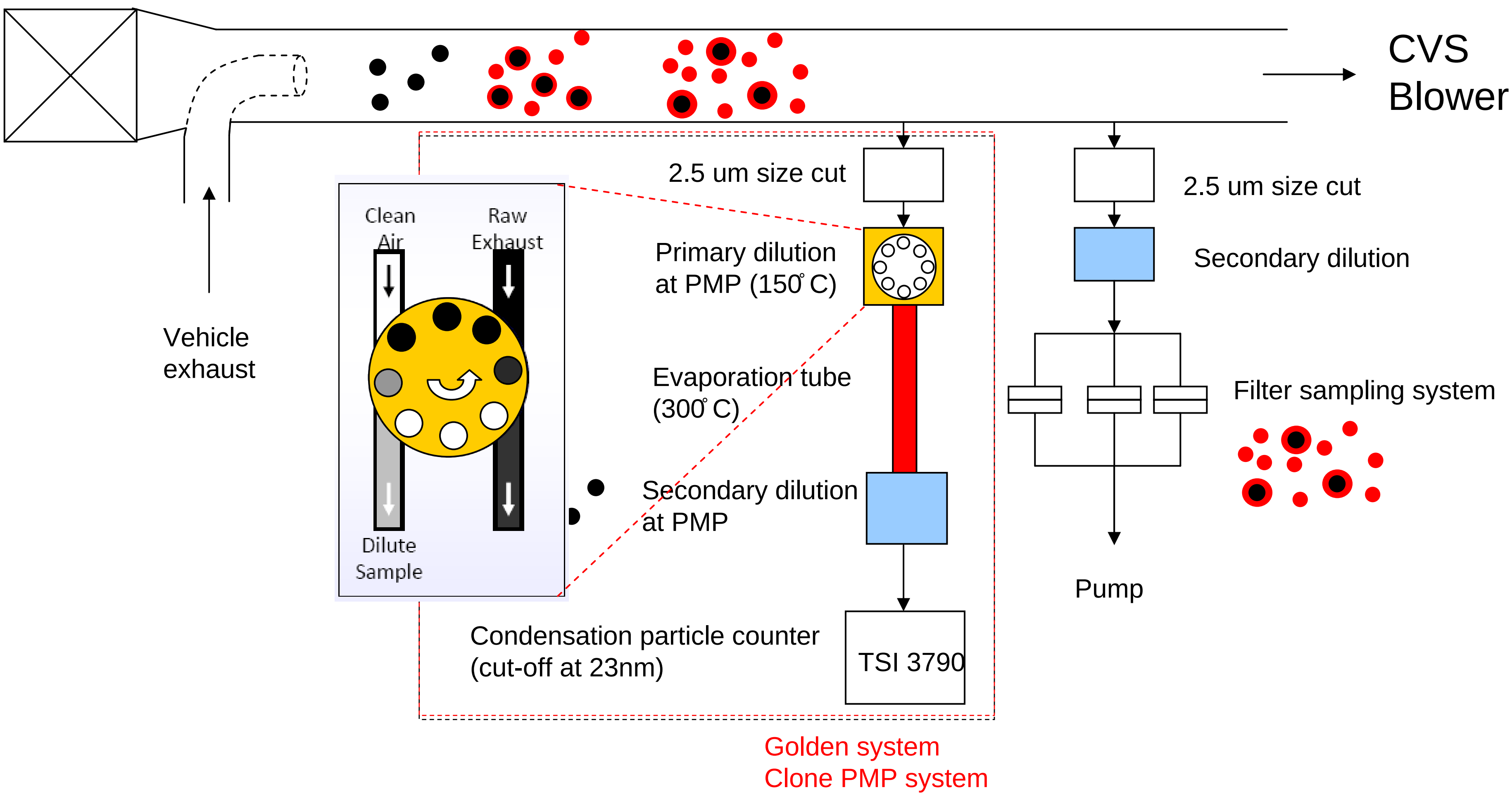
Dilution Air: Temperature, Absolute Pressure, Throat ΔP, Baro (Ambient), Flow, Dew Point (Ambient).

Exhaust: Temperature, ΔP (Exhaust-Ambient), Flow.

Engine Broadcast: Intake Temperature, Coolant Temperature, Boost Pressure, Baro Pressure, Vehicle Speed (mph), Engine Speed (rpm), Throttle Position, Load (% of rated).

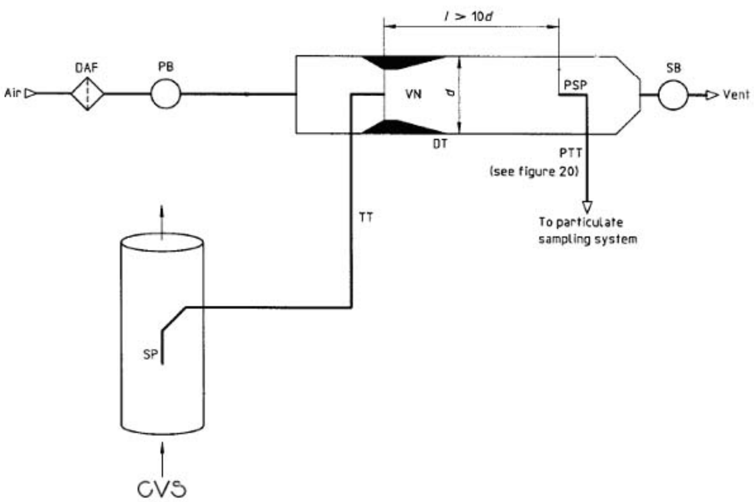
Cocker et al. Environ. Sci. Technol. **2004, 38, 6809-6816**

Gravimetric vs PMP measurements



Courtesy of W. Robertson for MD-19 diagram

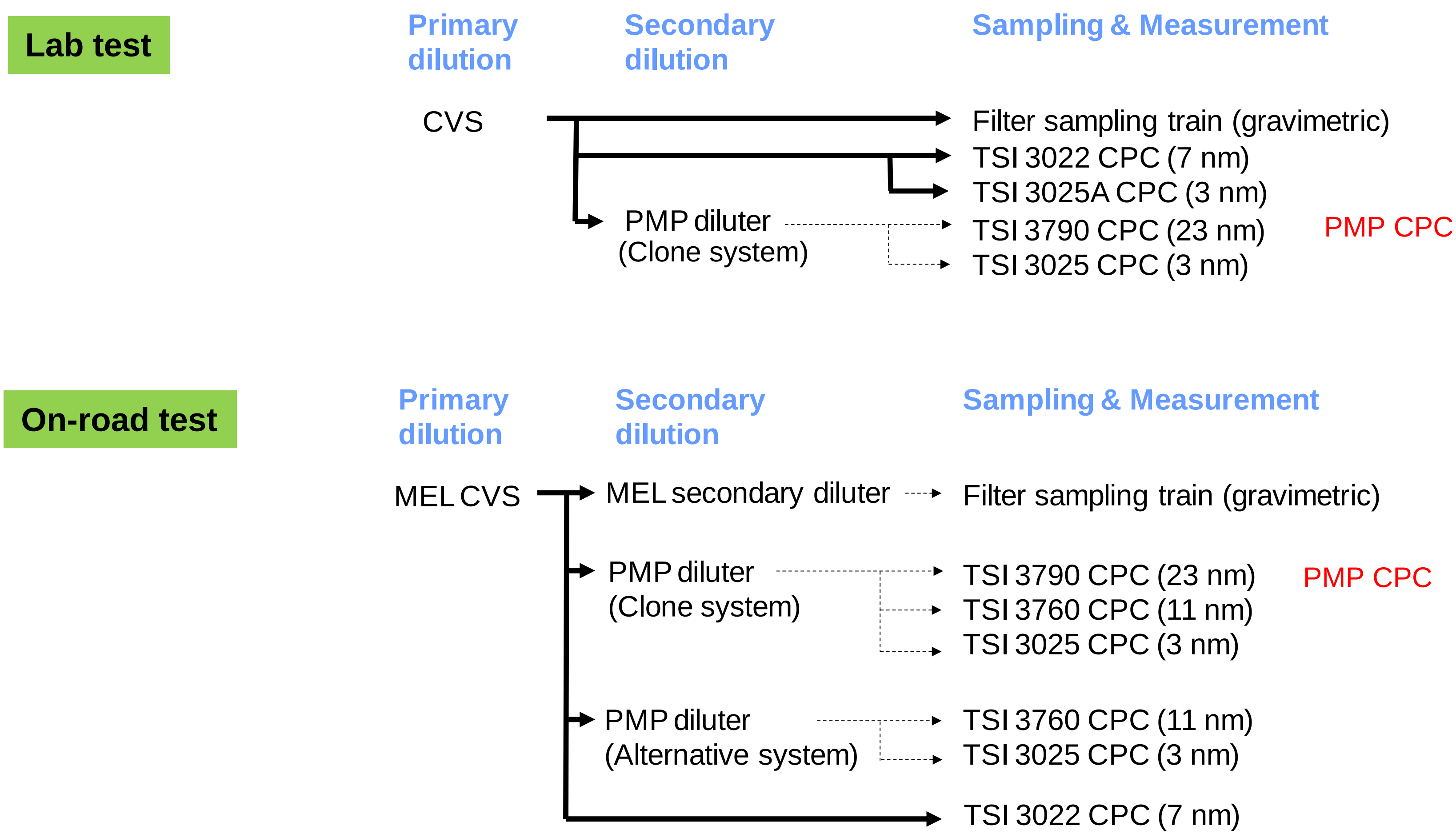
Alternative PMP system



Modified from ISO 8178 partial flow single venturi fractional flow sampler

	PND1				VPR	PND2	
PMP Design	DR	Temp (C)	Heat Length (in)	Flow (slpm)	Temp (C)	DR	Temp (C)
MEL	10	150	36	10	300	10	20
MD-19	30	150	6	20	300	10	20

Flow diagram of PM measurement system

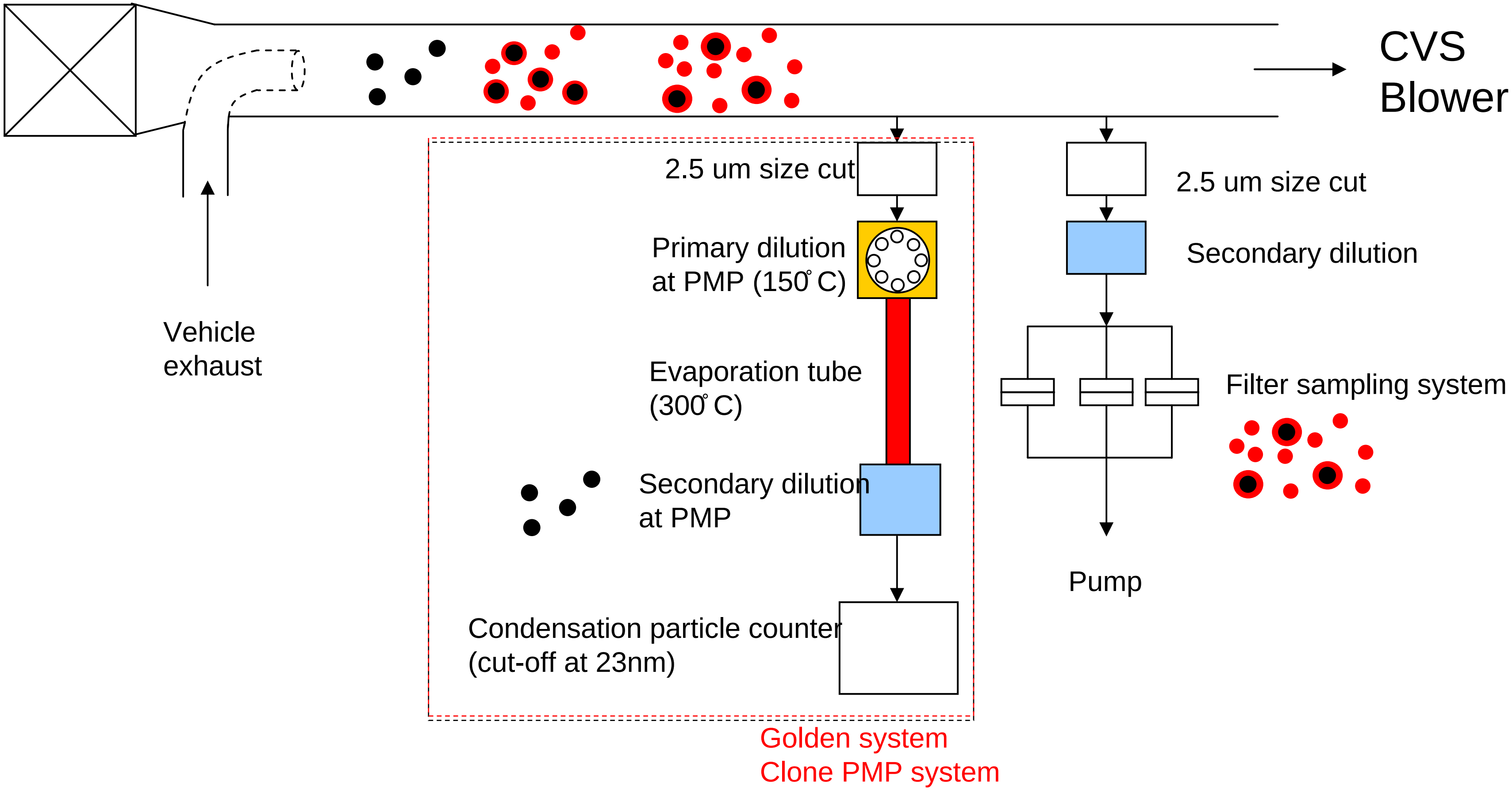


F-SMPS and EEPS at MEL CVS and PMP diluter

Experimental conditions

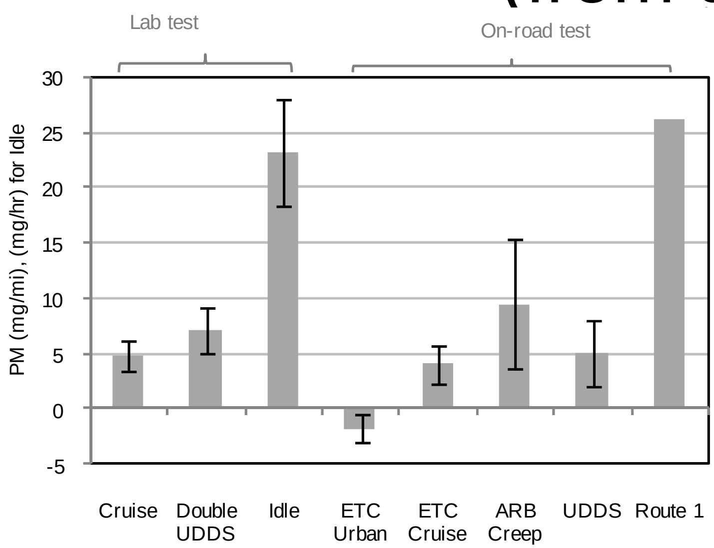
	Lab test	On-road test
Base	Chassis dynamometer	Mobile Emission Lab
PMP system	Clone system	Clone & Alternative systems
Vehicle	1999 International 4900	Freightliner class 8
Engine	International DT 466E (7.6L)	Caterpillar C-15 (14.6L)
Fuel	ULSD	ULSD
Lube oil	SAE 15W-40	SAE 15W-40
DPF	Engelhard DPX	JM CRT
Vehicle weight	27,000 lb	65,000 lb
Cycles	2x UDDS (35 min) 50 mph Cruise (45 min) Idle (40 min)	UDDS (18 min) ETC Cruise (10 min) CARB Creep (4 min) Flow-of-traffic

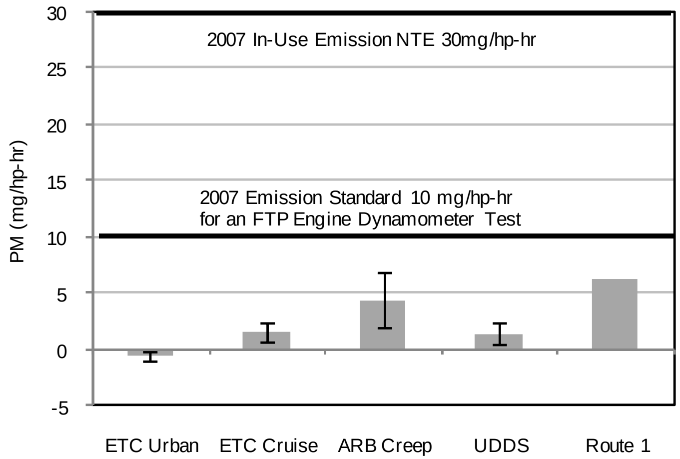
Integrated Results
(using Clone PMP system)

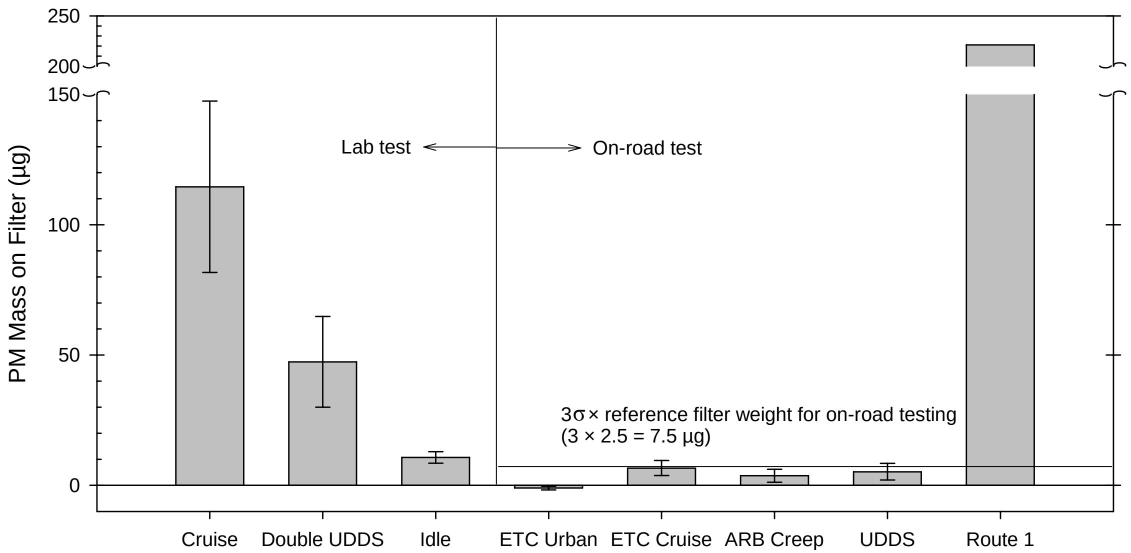


Courtesy of W. Robertson for MD-19 diagram

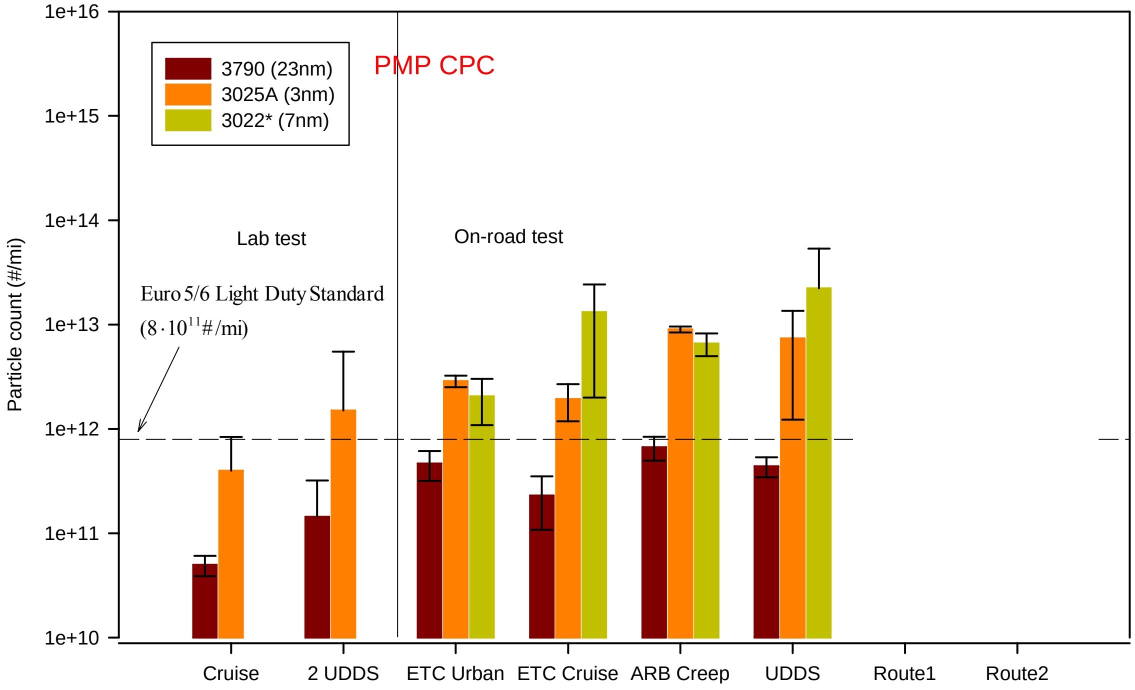
PM mass
(from gravimetric method)

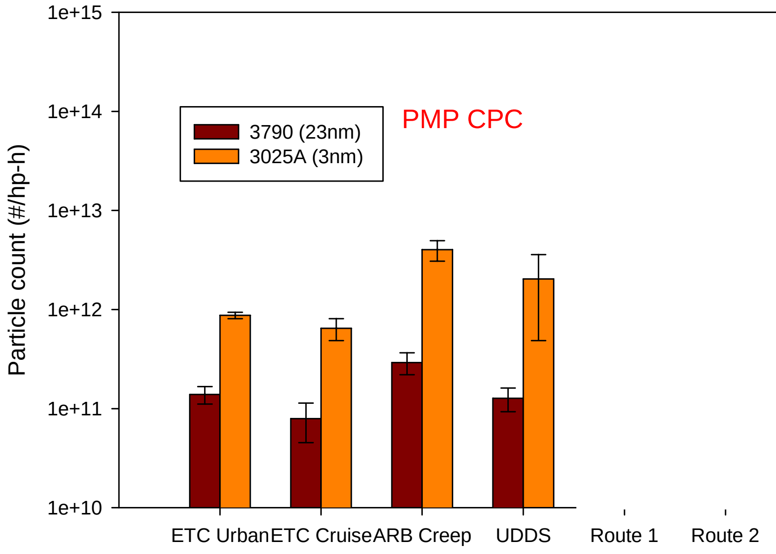


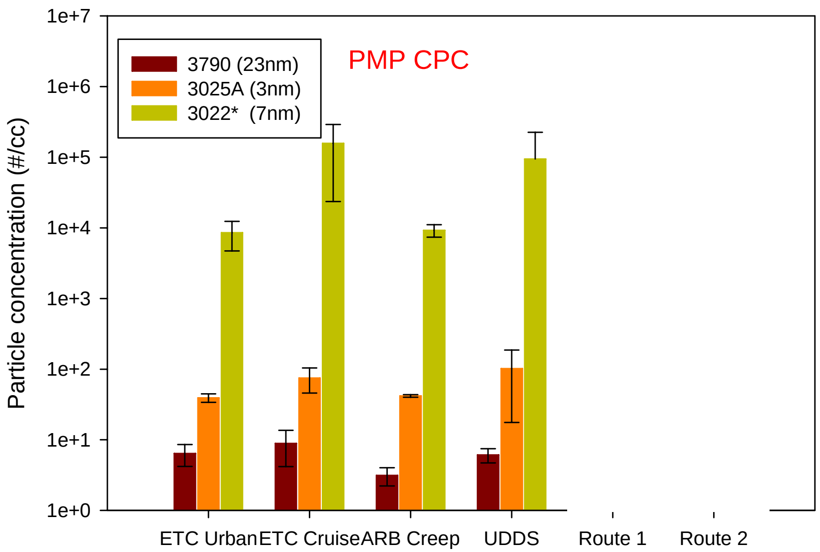




PM number

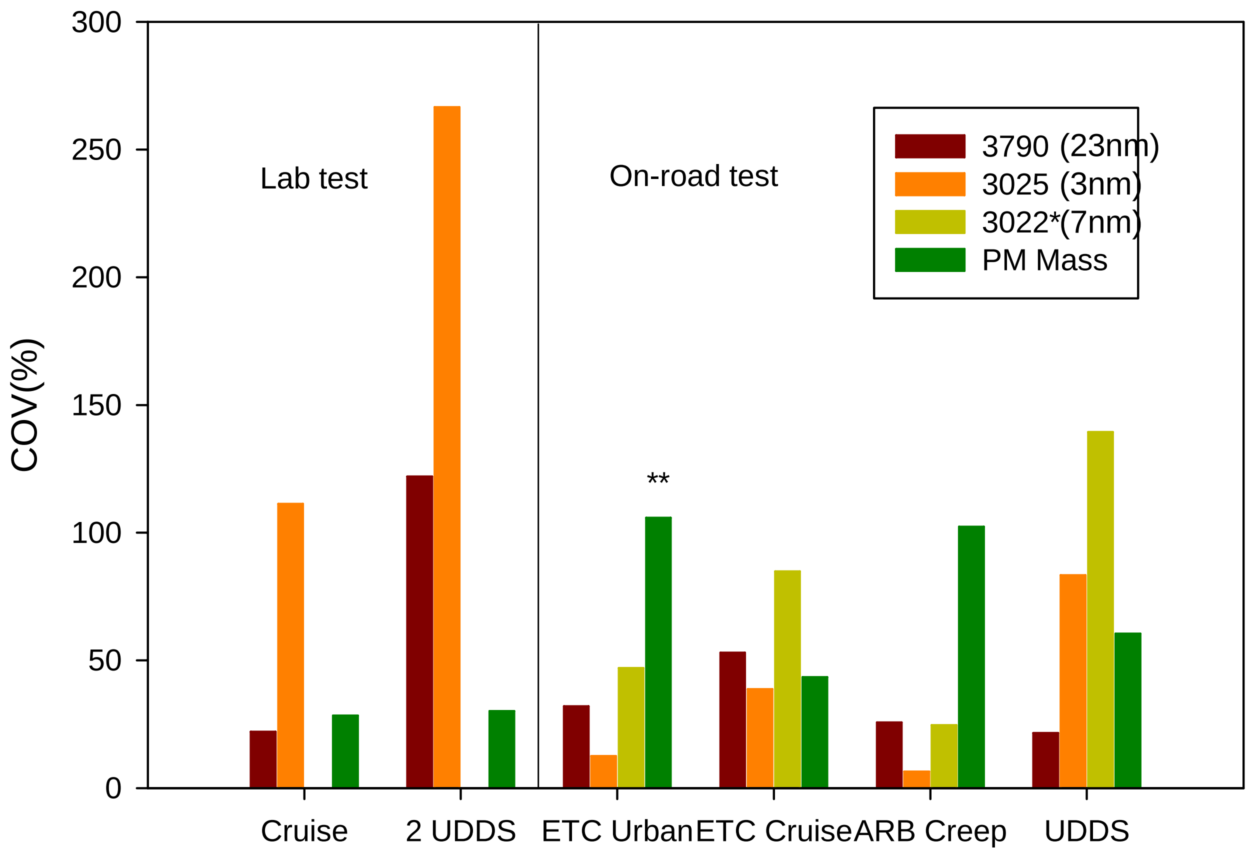






* Means at VS and ** means at MEL PMP system

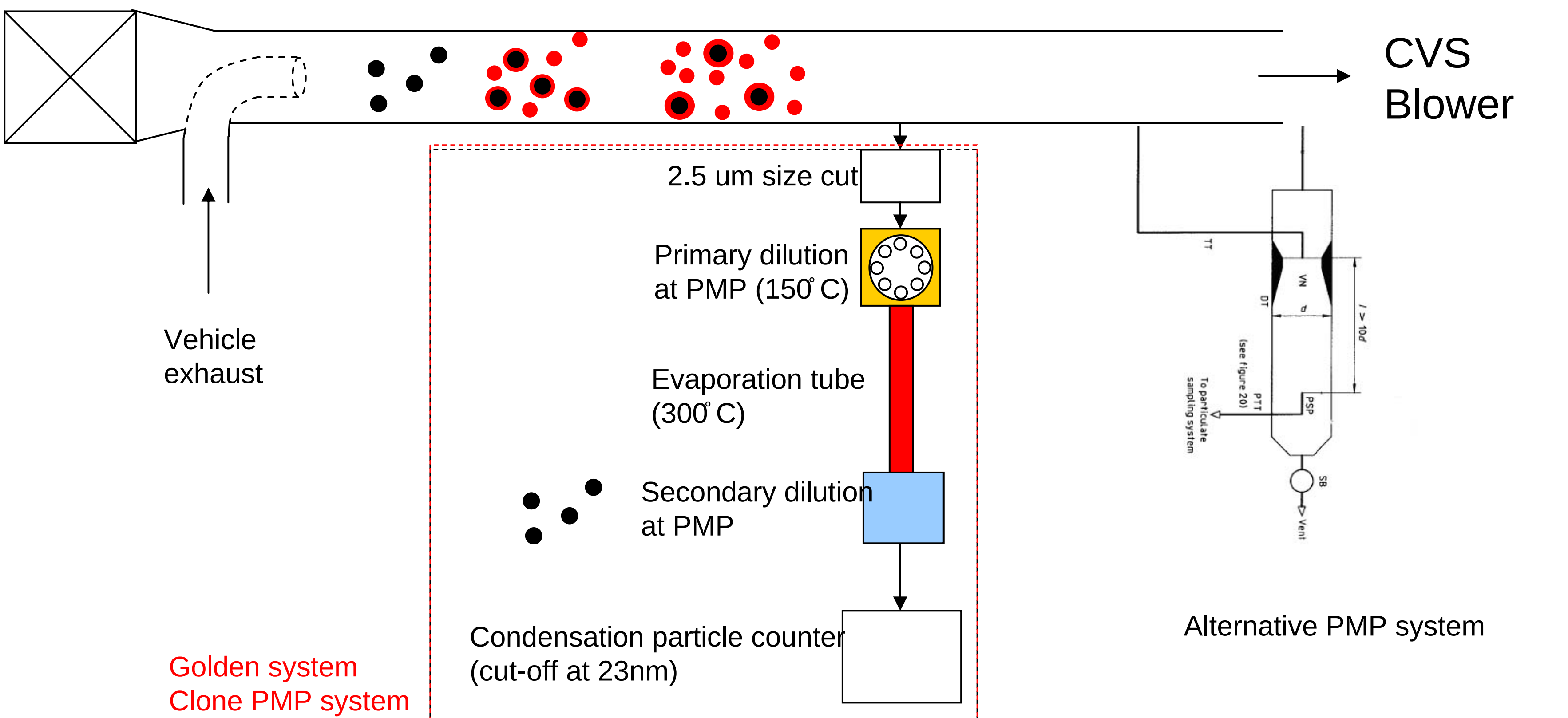
Coefficient of Variation (COV)



Results

(Real time data)

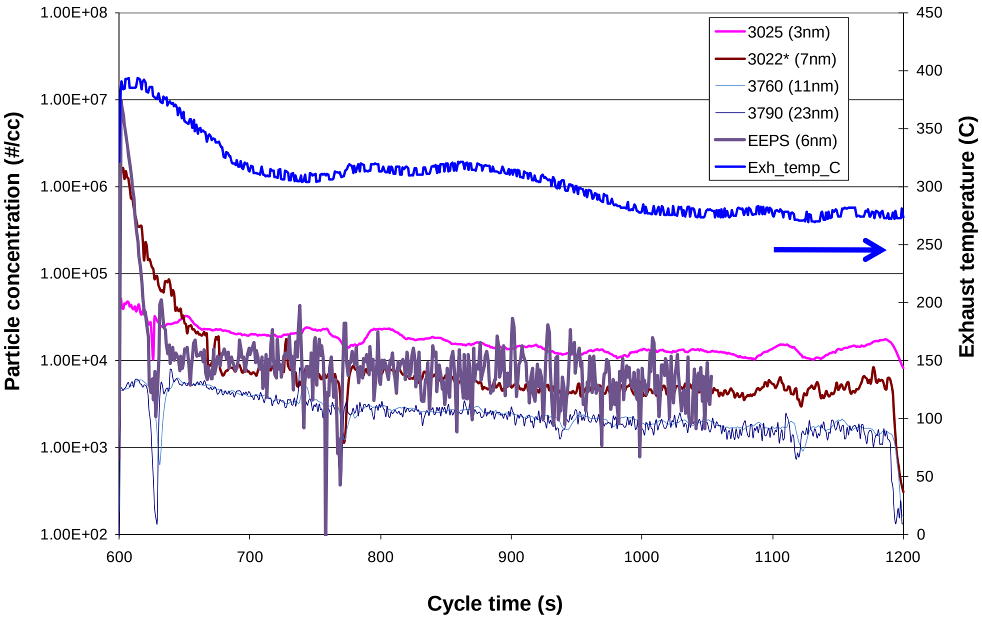
Concentrations normalized to those at CVS for comparison.



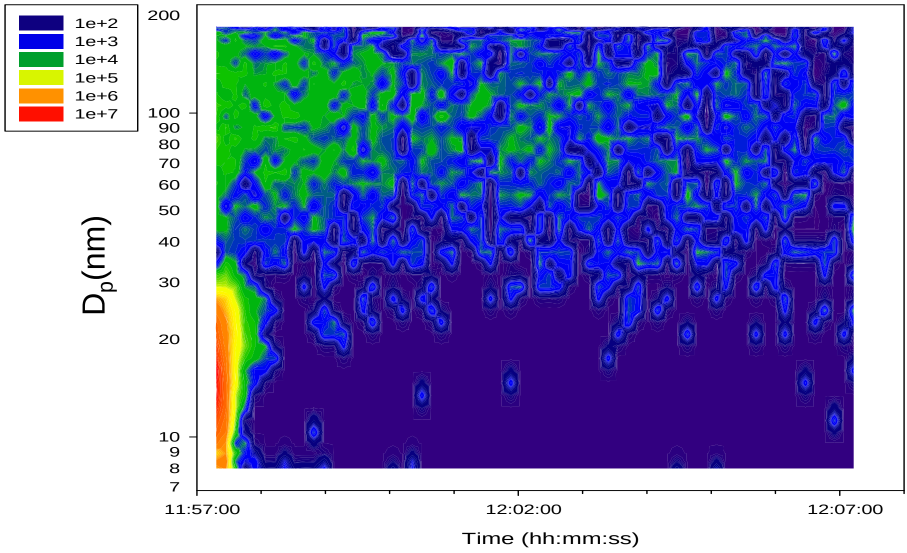
European Transient Cycle (ETC) Cruise

A spike showed up in the beginning of ETC cruise cycles all the time due to gear shift before the cycle.

CPCs Under PMP



F-SMPS at CVS



3 hypotheses:

- **Solid particle penetration-**
  - **-> Size distribution from previous studies using EEPS and DMS**
  - **-> Need to confirm with f-SMPS or nano-SMPS**
  - **-> Continuous ash particle emissions at DPF?-> Unlikely**
- **Partial evaporation of large particle**
- **Re-nucleation of sulfate**

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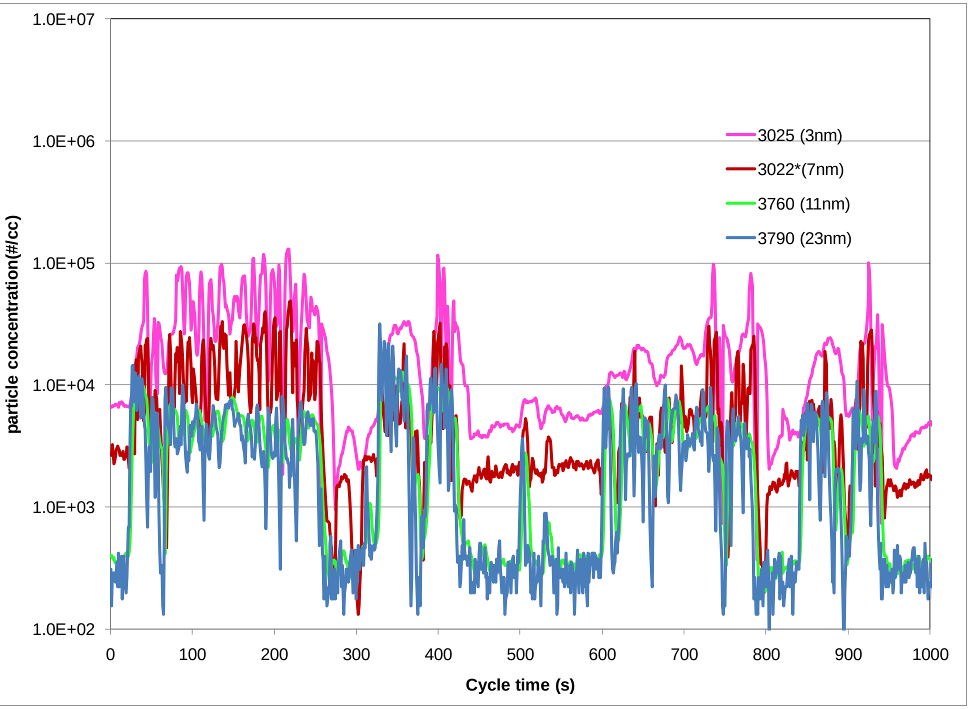
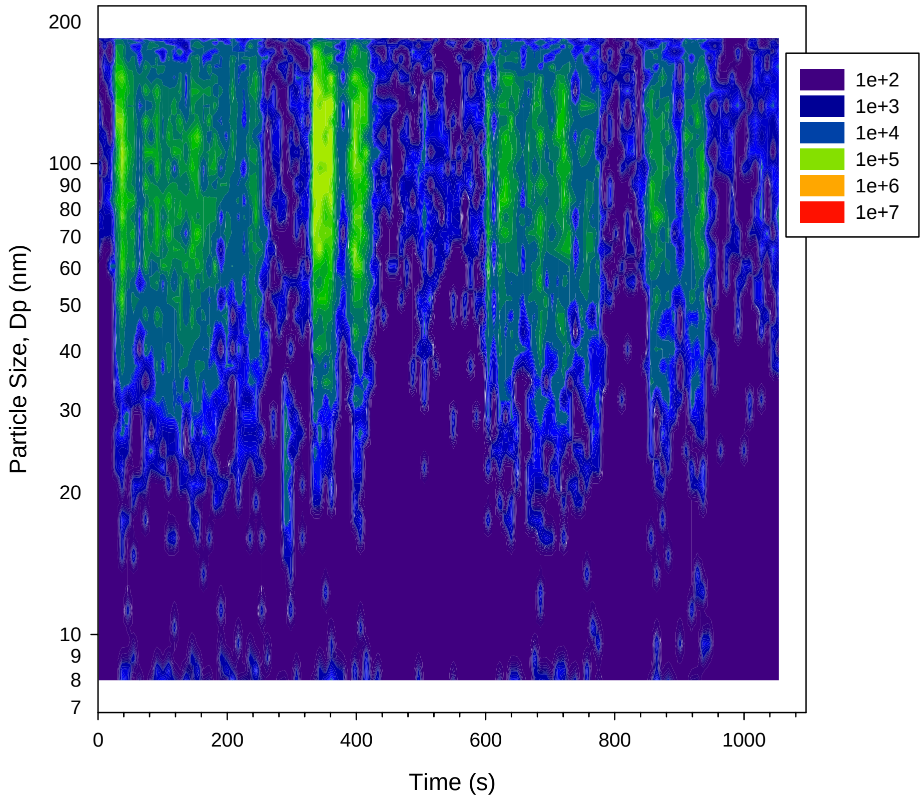
US EPA Urban Dynamometer Driving Schedule (UDDS a.k.a FTP 72 and LA-4)

CPCs under PMP

F-SMPS at CVS





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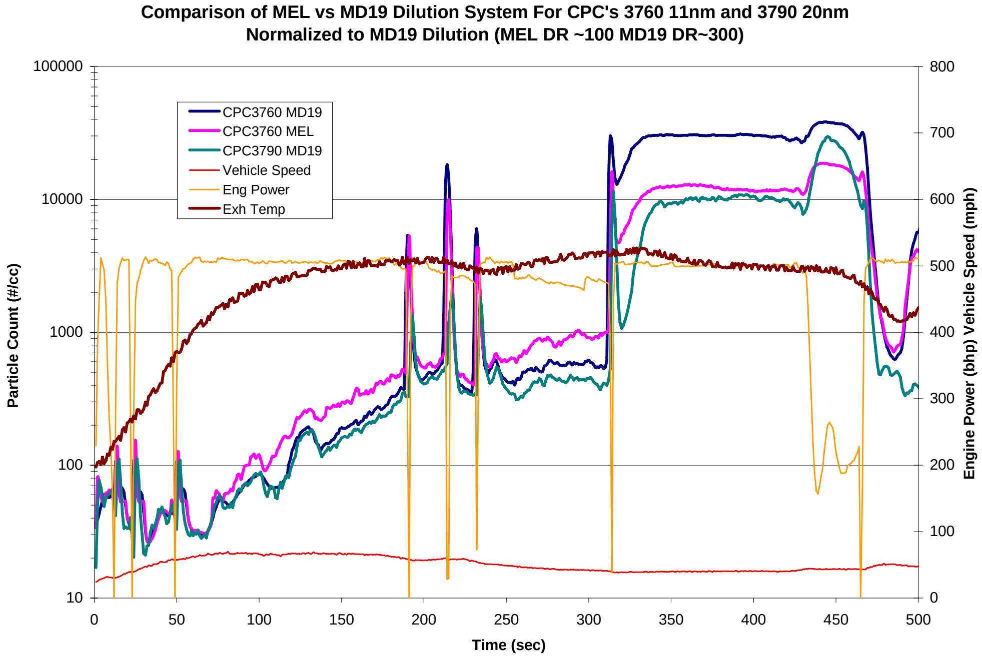
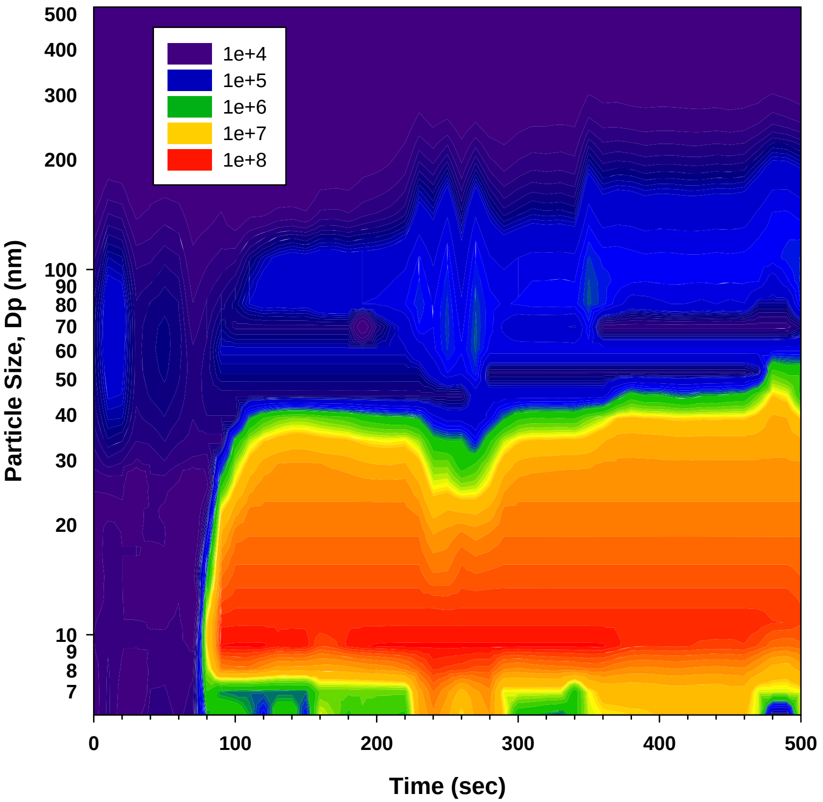
Real time data (flow-of-traffic)

CPCs under PMP

EEPS at CVS

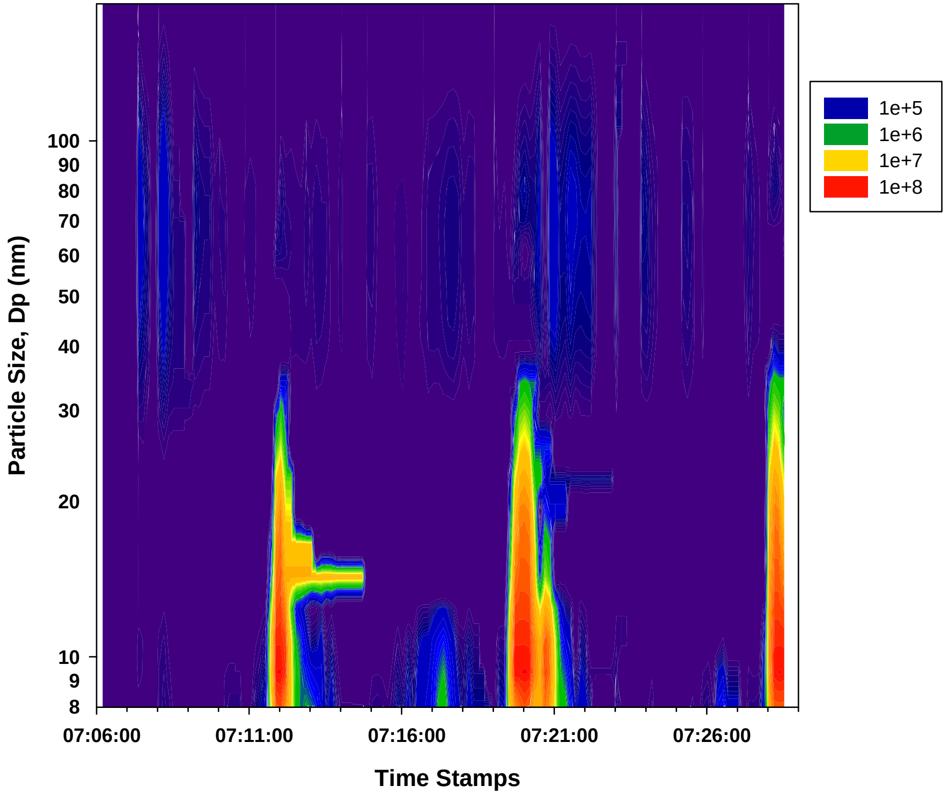
Hydrated sulfate concentration contributes to 45% of mass



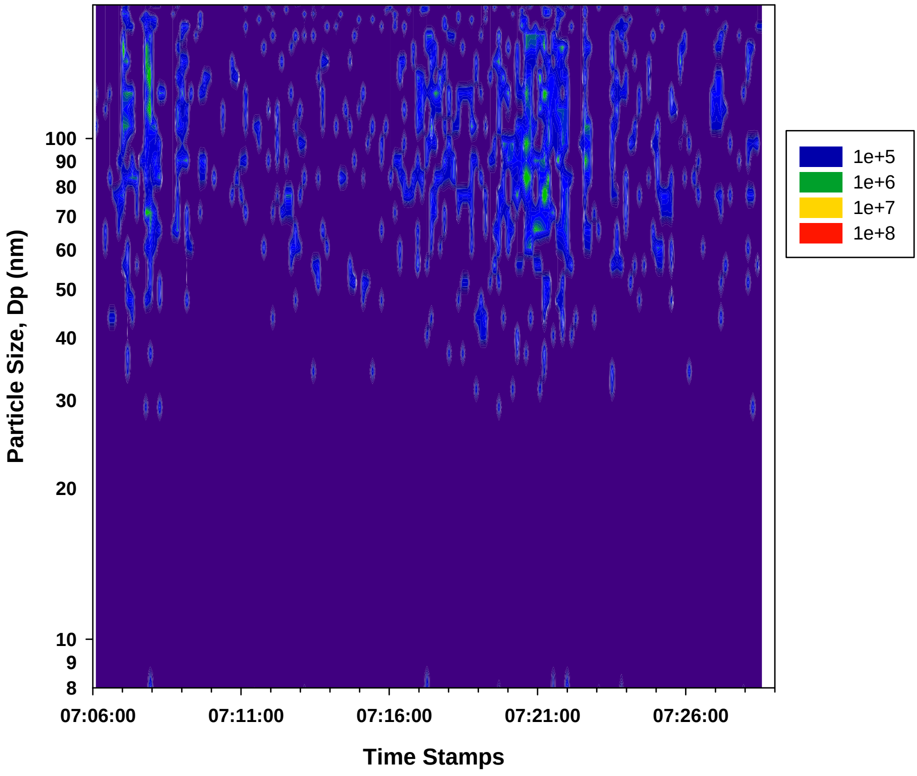


Real time data (flow-of-traffic)

EEPS at CVS



F-SMPS under Alternatve PMP system



Conclusion

- The overall results indicate that particle number can provide a more repeatable measurement with particle emission levels well below the 2007 U.S. PM mass standard.

Conclusion

- Under more aggressive, on-road driving conditions, significant nucleation was observed, with very high count levels below the PMP system. These particles had a large sulfate contribution that may not have been eliminated by the current PMP dilution system . This finding suggests that certification level tests are not sufficient to understand or characterize particle count levels that may occur on the road.

- Re-nucleation or penetration under PMP system should be understood and need further study.