Current Tailpipe PM Issues: A California Update

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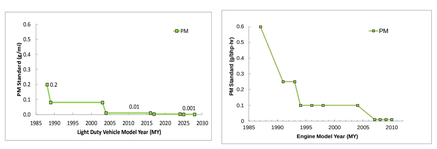
Outline:

Immense progress has been made in reducing combustion generated nano-particle emissions from vehicle exhaust. The interaction of clear policy direction and technology deployment have dramatically changed the nature of the Internal Combustion fleet in California. Both light duty and heavy duty PM emissions standards have dropped orders of magnitude.

California Emissions Standards for Light and Heavy Duty



The Air Resources Board is pursuing programs to understand the In-Use and Off-Cycle implications of the relatively new technologies used to accomplish these reductions.

This presentation provides some example vignettes of the many ongoing ARB projects to quantify and evaluate the effectiveness of these PM control programs:

- Comprehensive evaluation of Heavy Duty PM filters in California
- Construction of an apparatus for measuring near source effects of PM emissions from Parked Regenerations of Heavy Duty PM filters
- Recent work correlating alternative PM metrics with the current gravimetric method as applied to Light Duty Vehicles.

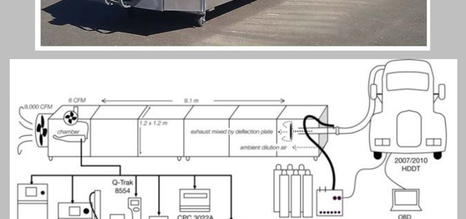
Studying Near-field Exposure from PM Filter Parked Regenerations

ARB has a longstanding commitment to researching potential secondary effects arising from emissions control technologies. Heavy-duty diesel engine and PM aftertreatement systems are increasingly moving to calibrations that minimize the need for user intervention as part of the PM filter regeneration process. However, some duty cycles can produce exhaust conditions unfavorable to passive PM filter regeneration and require the user intervention to initiate an active regeneration while the vehicle is parked or stationary.

The concentration and composition of PM immediately downwind during a parked regeneration is of interest for assessing possible impacts on vehicle drivers and other nearby personnel.

ARB has constructed a small scale wind tunnel to examine the plume evolution from PM filter equipped vehicles undergoing parked regenerations.

Initial proof of concept testing has been performed. Studies are underway to examine the downwind PM's parametric dependence on environmental factors and vehicle's PM filter history.



Quiros, et al, "Measuring particulate matter emissions during parked active diesel particulate filter regeneration of heavy-duty diesel trucks," Journal of Aerosol Science, Vol 73, pp.48-62, 2014, doi:0.1016/j.jaerosci.2014.02.002

Dwyer et al., "Ambient Emission Measurements from Parked Regenerations of 2007 and 2010 Diesel Particulate Filters," SAE Technical Paper 2014-01-2353, 2014, doi:10.4271/2014-01-2353

Comprehensive Evaluation of PM filters In-Use in California

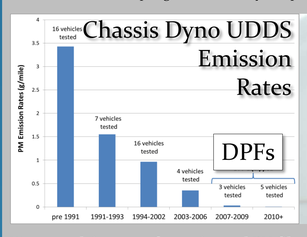
Basic questions:

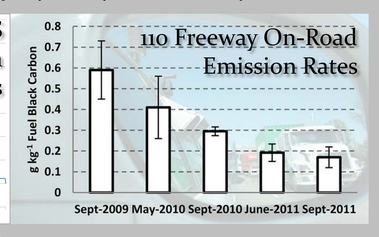
- Do PM filters increase the risk of truck fires?
- Do PM filters effectively reduce diesel PM by 85% or more?
- Do PM filters perform reliably in on-road applications?

Methodology:

Literature Review of potential relationship between PM filters and vehicle fires:
- Reports and statistics from National Fire Information Reporting System
- Studies conducted by staff at the Volpe National Transportation Systems Center in the U.S. Department of Transportation
- Studies by insurance companies and other organizations
- Assessed and summarized results from previous ARB investigations into truck fires where the truck in question was equipped with a retrofit PM filter

PM filter emissions data review:
In-house and Extramural emissions testing studies reviewed including both in depth laboratory testing and as-found characterization of the in-use fleet durability in the field:
- Engine and Chassis Dynamometer laboratory tests of heavy-duty engines and vehicles
- 5 years of ARB's SAE J1667 snap acceleration smoke (opacity) tests,
- On-road Plume Measurements from individual vehicles using ARB's mobile monitoring platform,
- On-road Heavy Duty Measurement System emissions profiles from University of Denver "tent"
- Black Carbon sampling from a freeway overpass by University of California, Berkeley





Warranty claims rates for engine and PM filter components
- Reviewed manufacturer data entered in the Emissions Warranty Information Reporting (EWIR) process to identify unscreened frequency of component failures reported during 100,000mi initial and extended warranty periods.
- Examined model years 2003 through 2011, as well as partial information available for 2012 & 2013.

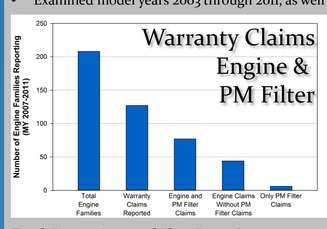


Table 1. Heavy-Heavy Duty (HHD, >33,000 lbs GVWR) Unscreened Warranty Claim Rates by Component Group for MY 2003-2011 Engines

	Percent Claims per Engines Sold							
	2003	2004*	2005	2006	2007*	2008	2009	2010*	2011
Injectors	6%	67%	8%	3%	8%	12%	40%	22%	14%
Engine / ECM / Other	16%	30%	22%	22%	90%	59%	32%	17%	11%
Turbocharger Related	15%	38%	22%	25%	18%	12%	17%	3%	3%
EGR	26%	42%	35%	33%	41%	44%	31%	12%	10%
EGR Cooler	30%	12%	5%	6%	15%	14%	21%	20%	14%
Exhaust Manifold	10%	9%	7%	1%	0%	1%	4%	4%	4%
DOC	0%	0%	0%	0%	0%	2%	1%	1%	0%
PM Filter Related	--	--	--	--	35%	18%	7%	8%	4%
SCR Related	--	--	--	--	--	--	--	20%	10%
Total HHD Sales	6487	5499	8889	7535	3524	4729	4062	2698	5232

ECM = engine control module, DOC = diesel oxidation catalyst, SCR = selective catalytic reduction
(*) Engine standard change (2004, 2.5 g NOx+HC/bhp-hr 2007, 0.01 g PM/bhp-hr. 2010, 0.02 g NOx/bhp-hr.
(--) Control technology not applicable for these model year ranges

Truck Inspections and Fleet Interviews
- **40 fleets** totaling **1927 trucks** of which **432 trucks** were examined during fleet visits with **386** of those having an installed PM filter
- Contacted all **21 fleets that had expressed PM filter concerns** to ARB at 2013 board meetings for follow up interviews and fleet inspection: **11 fleets responded** and followed through.
- Interviewed and inspected addition **29 randomly selected fleets**

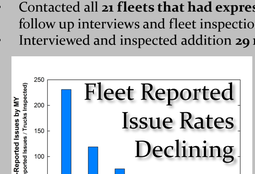


Table 2. Fleet-reported percentage of trucks experiencing engine issues by reported component. Actual issue rates for California trucks are likely lower than shown because the trucks tested were selected from fleets reporting problems with their trucks.

Model Year	EGR	Engine, ECM	TC	PM Filter Issue Associated With Engine Problem	PM Filter Issue, Cause Not Identified	SCR
Retrofits 1990-2006 121 Trucks	10%	20%	11%	10%	6%	--
OE 2007-2009 88 Trucks	10%	62%	23%	32%	13%	--
OE 2010-2013 177 Trucks	7%	9%	0%	1%	0%	2%

Roadside Inspections paired with Operator Interviews
- Check for PM residue in exhaust stack
- Check Malfunction Indicator Lights
- Inspect PM filter housing for proper installation
- Conduct Opacity Test to screen PM emissions
- Document engine, vehicle and vocational information
- Ask operators if they have or are experiencing PM filter issues
- **621** truck inspections conducted which included **587** PM filter equipped trucks

Survey of PM filter supply chain
- Contacted Retrofit PM Filter installers, retrofit manufacturers and OE truck dealers
- Mail out surveys used to collect installation and in-field issues experienced

Conclusions:

- PM filters do not increase the likelihood of truck fires and are manufactured in accordance with federal and state safety requirements.
- PM filters are effective in removing more than 98 percent of toxic diesel PM emissions.
- PM filters are operating properly, and most trucking fleets are not having problems with their engines or PM filters.
- Some fleets are experiencing problems with their PM filters, but engine durability issues and inadequate maintenance practices are the primary reasons for these problems.

Recommendations:

1. **Continue Working to Hold Manufacturers Accountable.**
   Staff and testing resources are being dedicated to new in-use emission measurement programs to better enforce engine certification standards. Additionally, staff is considering amendments to ARB's Emissions Warranty Information Reporting regulations to hold manufacturers accountable for high warranty claims that can result in excess emissions.
2. **Educate Truck and Bus Owners and Operators.**
   Staff is working with industry to identify best preventive maintenance practices to maintain properly functioning engines, and to disseminate this information to fleets, dealers, and repair shops through enhancements to ARB's outreach and education activities, and through trucking and other industry organizations.
3. **Enhance Certification Programs.**
   Staff is developing improvements to ARB's certification program requirements that will provide broader in-use protections, greater warranty protections, and better assurances of engine component durability over a vehicle's life.
4. **Develop Stronger Inspection and Maintenance (I/M) Requirements.**
   Staff is developing a proposal to expand heavy duty truck I/M requirements to help ensure these vehicles and their emissions control systems are properly maintained and achieving in-use the desired emissions and localized risk reductions.
5. **Continue to Provide Assistance to Fleets Operating Retrofits in On-Road and Off-Road Applications.**
   Staff will continue to investigate fleet concerns with retrofit performance in on-road and off-road applications and provide assistance to help ensure proper retrofit operation.

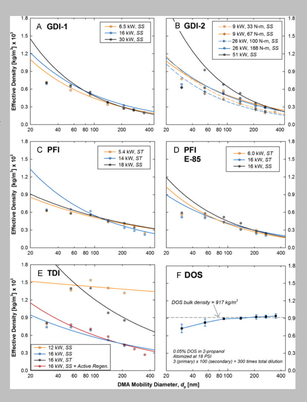
Full Report available for download:

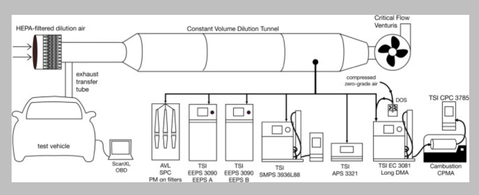
http://www.arb.ca.gov/msprog/onrdiesel/documents/DPFEval.pdf

Examining Light Duty Vehicle PM by Various Metrics

ARB has recently conducted studies of PM emitted by various light duty vehicle engine/ aftertreatment technologies. Comparison was made with the reference gravimetric method to assess correlation, biases, and variability origin.

Measurements of the size dependent Effective Particle Density were collected to using the setup below for use as input parameters for subsequent Integrated Particle Size Distribution (IPSD) method PM mass determinations.



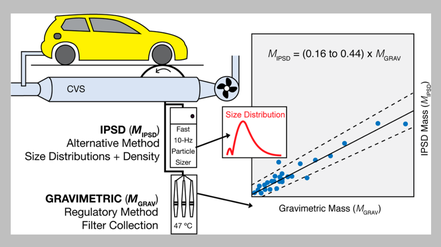


Effective particle density measurement setup

Effective particle density was found to generally increase at small particle diameters but also displayed an engine/aftertreatement technology dependence. Most vehicle technologies examined showed relatively little variation of the Effective Particle Density function with duty cycle. The exception was the turbocharged direct injection diesel (TDI) with PM filter aftertreatment which displayed strong duty cycle dependent variations that merit further investigation.

Application of Effective Particle Density to PM mass determination:

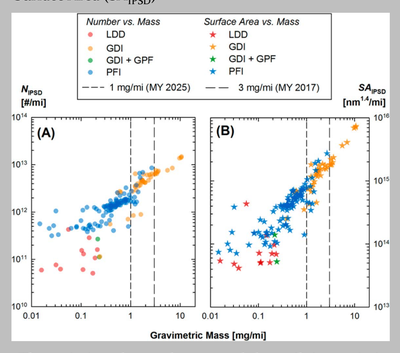
Strong correlation was observed for IPSD derived PM mass with respect to the gravimetric method. However the IPSD method applied using fast particle sizer PM distributions consistently underestimated the total PM mass.



Inclusion of larger diameter particle s improved the IPSD/Gravimetric correlation.

The breadth of particle diameters required for improved mass correlation necessitated simultaneous use of more than one particle sizing technology to span the range.

In addition to IPSD mass, other particle parameters calculated from the instrumental measurements and evaluated for their correlation with the Gravimetric Method including total particle numbers (N_{IPSD}) and Surface Area (SA_{IPSD})



The variation observed suggested that tailpipe emission rate changes within a given test vehicle were more important than method-to-method variability.

Quiros, et al, J.of Aerosol Sci., Vol 83, May 2015, pp 39–54, doi:10.1016/j.jaerosci.2014.12.004

Quiros, et al, Environ. Sci. Technol. 2015, 49, 5618–5627, DOI: 10.1021/acs.est.5b00666

Summary

Internal Combustion engines will remain important during the e-Mobility demonstration and e-Mobility phase-in periods and will likely continuing in niche applications for a significant time thereafter.

Robust technologies exist for meeting stringent PM standards in both light and heavy duty sectors. Well controlled gravimetric measurements appear to give similar levels of PM emission control as more sophisticated on-line instrumental methods.

The high removal efficiency of PM emission controls underscores the necessity of engine and emission control system durability to prevent a deterioration-based return to uncontrolled emission rates. Actual In-Use performance is very important to realizing the expected emissions gains promised by the stringent PM standards.

ARB has identified In-Use emissions performance improvement measures as potentially higher yield than a further lowering of On-Road PM standards.

Future Work to Promote Heavy Duty In-Use Durability:

- Continue full implementation of Heavy Duty On-Board Diagnostics (OBD) for prompt identification and efficient repairs. (2013 first year of full phase-in.)
- Continue conducting regular laboratory robustness investigations of as-implemented OBD algorithms.
- Develop an Inspection and Maintenance (I/M) program for the Heavy Duty sector.
- Seek expanded regulatory authority to initiate recalls based on high reported emissions warranty claim rates.
- Extend Heavy Duty emissions warranty period to correspond more closely to typical vehicle useful life.

California Environmental Protection Agency
Air Resources Board