Total and Solid Particle Mass and Number Emissions from a 2010 Vehicle Equipped with a GDI Engine Using 11 Different Fuels

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Particulate matter (PM) emission from passenger cars equipped with gasoline direct injection (GDI) engines is a subject of great concern in the United States and Europe. Discussions and cost/benefit analyses are still underway to establish the solid particle number regulatory limit for Euro 6 in relation to vehicles equipped with GDI engines. California Air Resources Board (CARB) recently released modified LEV III regulations, where passenger cars are required to meet the 2017 and 2022 proposed limits of 3.8 mg/km and 1.9 mg/km, respectively. The 2017 and 2022 limits also include optional solid particle number standards of 3.8×10^{12} part./km and 1.9×10^{12} part./km, respectively, using the EPA FTP-75 cycle. Furthermore, U.S. EPA is currently looking to tighten emissions from vehicles as a part of Tier 3 regulations including a new limit on PM emissions.

In light of the high interest in GDI PM emissions, this work focuses on characterizing PM emissions from a 2010 vehicle equipped with a GDI engine using 11 different commercially available gasoline fuels in the U.S. The 2010 GDI engine uses a wall guided fuel injection system and operates at a stoichiometric fuel-air mixture to take advantage of an exhaust three-way-catalyst to reduce gaseous regulated pollutants. This work compliments and expands on our work performed last year on a 2009 GDI engine.

A substantial difference in both total and solid particle mass and number emissions was observed using the different fuels. Fuel volatility and aromatic content seem to play an important role in PM formation. Also, significant difference in particle emissions were found between the 2009 tested last year and the 2010 vehicle. A detail paper on this work is planned for the SAE World Congress in March, 2012.

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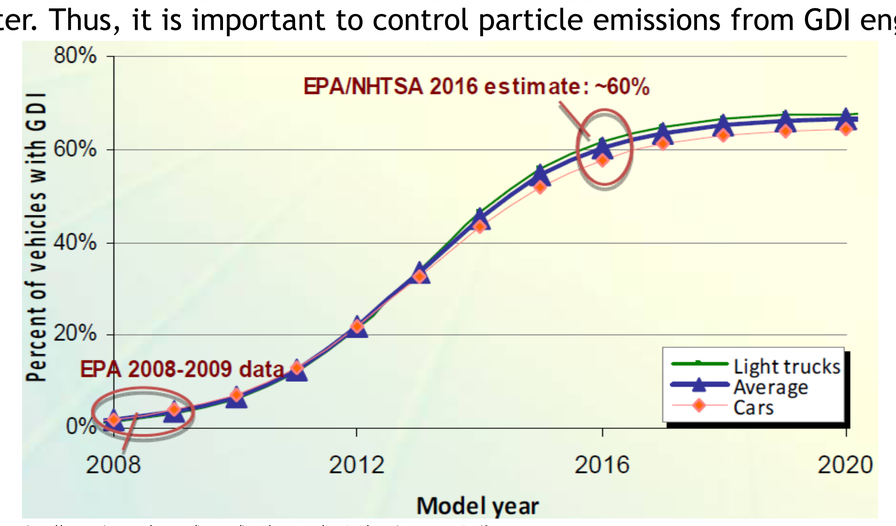
Background

Stoichiometric gasoline direct injection (GDI) engines with three-way catalysts are expected to have a significant market penetration in the United States by 2016. This is mainly driven by fuel economy and green house gas regulations. However, GDI engine technology is known to emit higher particle emission than typical multiport fuel injection gasoline engines or diesel engines equipped with high efficiency exhaust particle filter. Thus, it is important to control particle emissions from GDI engines.



http://www.arb.ca.gov/msprog/levprog/leviii/meetings/051810/pm_disc_paper-v6.pdf

Regulations

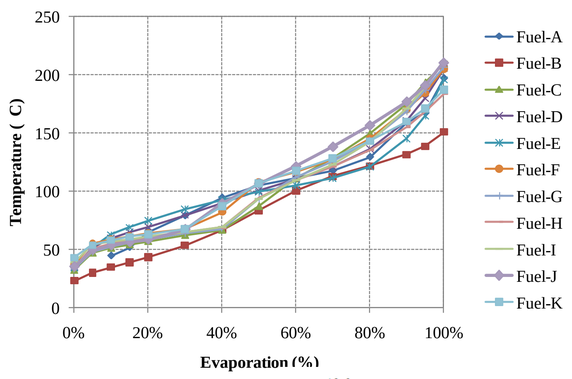
- In the US, particulate matter (PM) is regulated on a mass-basis, and no number-based regulation is currently in place. The current PM emissions limit is 6.3 mg/km.
- New California Air Resources Board (CARB) LEV III regulations target PM emissions limits of:
  - 3.8 mg/km by 2017
  - 1.9 mg/km by 2020-2022
  - 0.6 mg/km by 2025
- US EPA Tier 3 is currently under development and may adapt a similar approach to CARB. Both CARB and EPA will be looking at the issue of particle number in the future
- European Union limit is 4.5 mg/km by 2014. The exact solid particle number limit for GDI engines is still being considered for 2014, but will be at 6 x 10^{11} part./km if treated like diesel

Problem Statement/Objectives

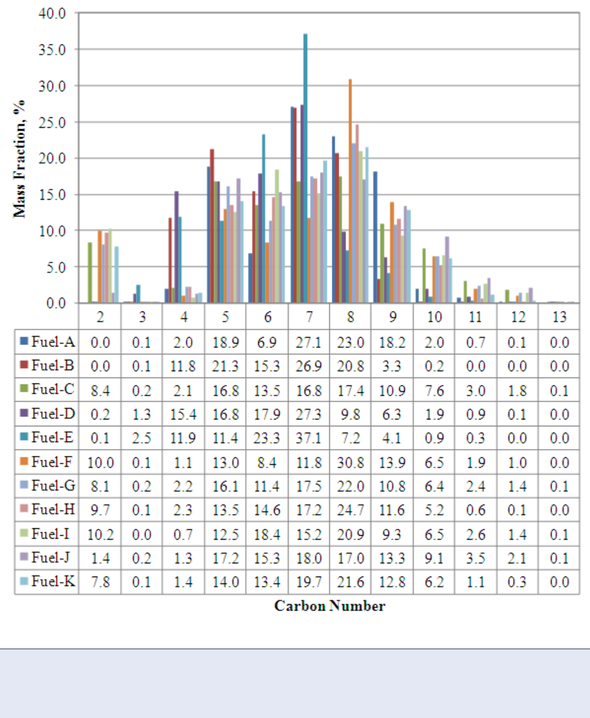
- In light of the upcoming regulations, we have been looking at how commercially available fuels affect particle emissions from GDI engines
- Last year, we showed that fuel volatility and double-bond equivalent can have a big influence on particle emissions from a 2009 model year vehicle equipped with a GDI engine
- This year, we investigated the effect of eleven different fuels on particle emissions from a 2010 model year vehicle equipped with a GDI engine. We measured:
  - Total PM and Soot Mass
  - Solid Particle Number (> 2.5 nm and > 23 nm)
  - Solid Particle Size Distribution

Fuels

- Most of the fuels were collected from various gas stations in the US

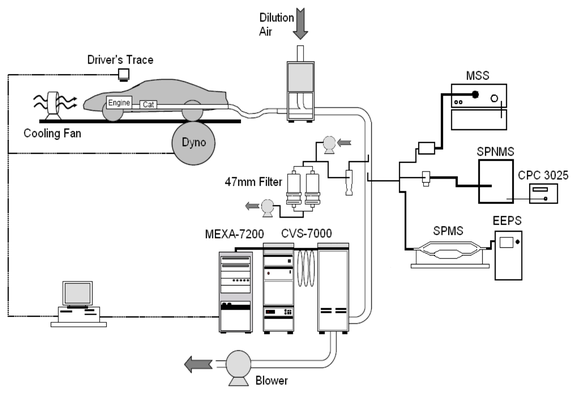


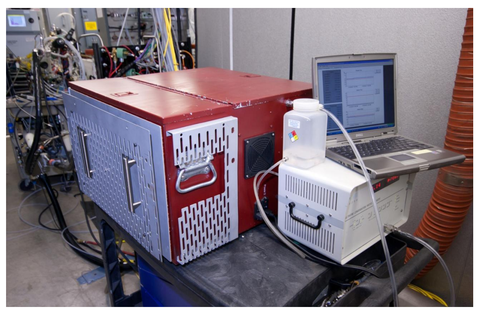
	CARBON wt%	HYDROGEN wt%	OXYGEN wt%
Fuel-A	86.3	13.7	-
Fuel-B	87.0	13.0	-
Fuel-C	83.1	13.6	3.3
Fuel-D	85.8	14.2	-
Fuel-E	85.4	14.6	-
Fuel-F	82.9	13.8	3.3
Fuel-G	83.6	13.6	2.8
Fuel-H	83.4	13.5	3.1
Fuel-I	82.6	13.8	3.6
Fuel-J	86.6	13.4	-
Fuel-K	83.0	13.5	3.5



	2	3	4	5	6	7	8	9	10	11	12	13
Fuel-A	0.0	0.1	2.0	18.9	6.9	27.1	23.0	18.2	2.0	0.7	0.1	0.0
Fuel-B	0.0	0.1	11.8	21.3	15.3	26.9	20.8	3.3	0.2	0.0	0.0	0.0
Fuel-C	8.4	0.2	2.1	16.8	13.5	16.8	17.4	10.9	7.6	3.0	1.8	0.1
Fuel-D	0.2	1.3	15.4	16.8	17.9	27.3	9.8	6.3	1.9	0.9	0.1	0.0
Fuel-E	0.1	2.5	11.9	11.4	23.3	37.1	7.2	4.1	0.9	0.3	0.0	0.0
Fuel-F	10.0	0.1	1.1	13.0	8.4	11.8	30.8	13.9	6.5	1.9	1.0	0.0
Fuel-G	8.1	0.2	2.2	16.1	11.4	17.5	22.0	10.8	6.4	2.4	1.4	0.1
Fuel-H	9.7	0.1	2.3	13.5	14.6	17.2	24.7	11.6	5.2	0.6	0.1	0.0
Fuel-I	10.2	0.0	0.7	12.5	18.4	15.2	20.9	9.3	6.5	2.6	1.4	0.1
Fuel-J	1.4	0.2	1.3	17.2	15.3	18.0	17.0	13.3	9.1	3.5	2.1	0.1
Fuel-K	7.8	0.1	1.4	14.0	13.4	19.7	21.6	12.8	6.2	1.1	0.3	0.0

Experimental Setup/Particle Instruments



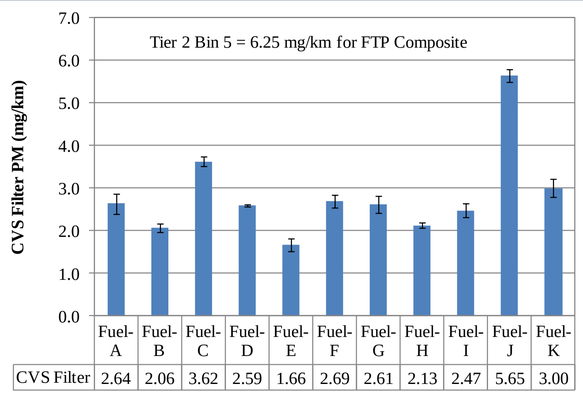


SwRI Catalytic-Stripper-Based Solid Particle Number Measurement System (SPNMS)

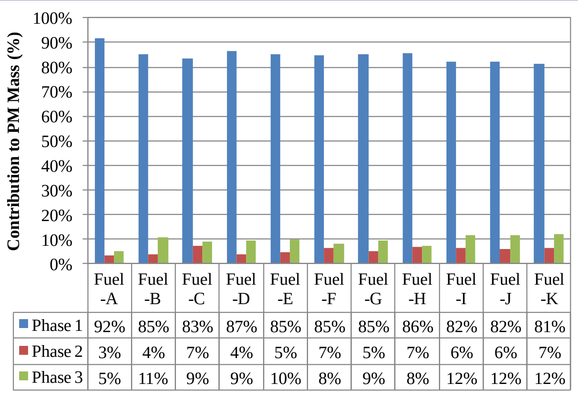
SwRI Solid Particle Sampling System (SPSS) Plus TSI Engine Exhaust Particle Sizer (EEPS)

AVL Micro-Soot Sensor (MSS)

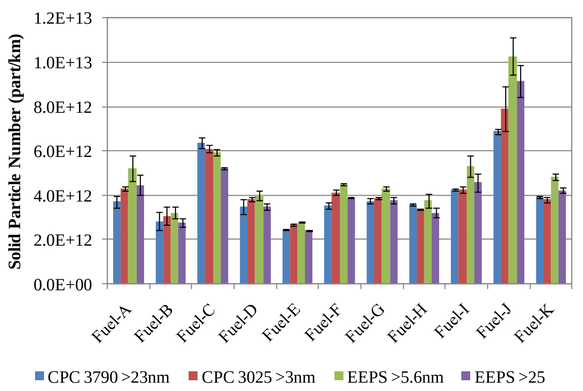
Results (Phase 1 , 2, and 3 of the FTP Transient Cycle)

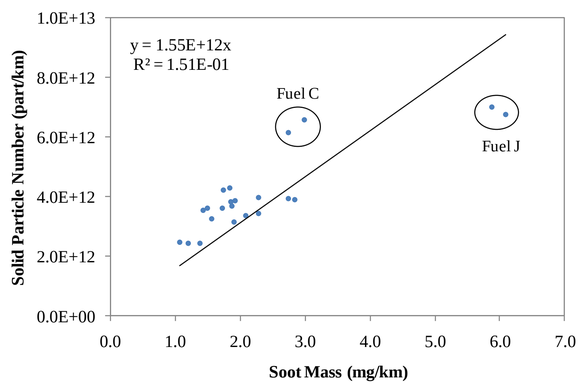


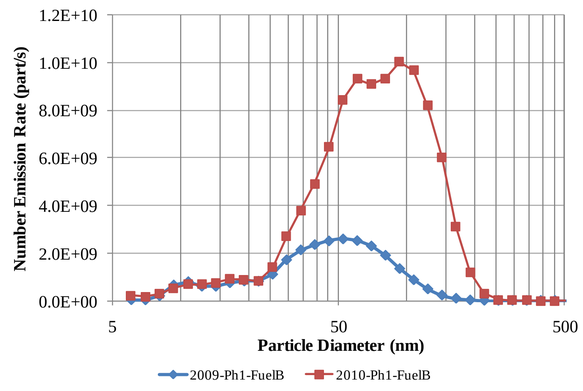
	Fuel-A	Fuel-B	Fuel-C	Fuel-D	Fuel-E	Fuel-F	Fuel-G	Fuel-H	Fuel-I	Fuel-J	Fuel-K
CVS Filter	2.64	2.06	3.62	2.59	1.66	2.69	2.61	2.13	2.47	5.65	3.00

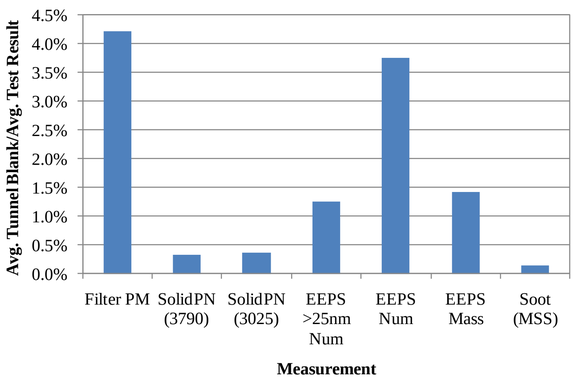


	Fuel -A	Fuel -B	Fuel -C	Fuel -D	Fuel -E	Fuel -F	Fuel -G	Fuel -H	Fuel -I	Fuel -J	Fuel -K
Phase 1	92%	85%	83%	87%	85%	85%	85%	86%	82%	82%	81%
Phase 2	3%	4%	7%	4%	5%	7%	5%	7%	6%	6%	7%
Phase 3	5%	11%	9%	9%	10%	8%	9%	8%	12%	12%	12%









Conclusions

- All fuels met the current limit on PM mass in the US, and the majority will meet the 2017 limit, with the 2010 vehicle. More PM mass reduction is needed for 2020 and beyond. Depending the fuel used, PM mass changes by as much as factor of the three. More volatile fuel produced less PM.
- On a solid-particle number basis (although based on the FTP and not NEDC), non of the fuels will enable the vehicle to meet a solid particle number limit of 6 x 10^{11} part./km limit.
- Substantial difference in particle emissions was observed between two different but modern GDI vehicles
- Soot mass produced the lowest artifact when compared with other particle metrics
- A detailed publication about this work is planned for 2012 SAE Congress

Acknowledgements

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