

The GDI Engine: Features, Emissions, and Effect of Fuel Composition

Allen L. Robinson

Carnegie Mellon University

Funding: ARB, EPA, and CRC

Presented at Health Effects Institute Annual Conference, Alexandria VA, April 30-May 2, 2017.

What is GDI?

Port Fuel Injection (PFI)



What is GDI?

Port Fuel Injection (PFI)



GDI = Gasoline Direct Injection



GDI Benefits:

- (1) Higher compression ratio due to evaporative cooling effect reducing compression temperature and knock onset
- (2) Greater flexibility in valve operations

Wall vs. Spray Guided GDI

Wall Guided GDI

Spray Guided GDI



GDI vehicles rapidly penetrating the fleet

• Market share of new vehicles with GDI >50% in 2016



Rapid change in technology.

What are implications for emissions and air quality?

Vehicle emissions in context



Increasingly stringent regulations (left) have led to large decreases in CO, NO, HC emissions from on-road fleet (right).

Slide from Tim Wallington, Ford, HEI Sponsors Meeting

Substantial improvements in ambient air quality



Large reductions in VOC concentrations measured in ambient air near Los Angeles from 1960-2010.

Slide from Tim Wallington, Ford, HEI Sponsors Meeting

Emissions and air quality



GDI vs. PFI: No differences in emissions regulated gaseous pollutants



(Saliba et al. EST 2017)

Carnegie Mellon University

LEV = low emission vehicle ULEV = ultra-low-emission vehicle SULEV = super ultra-low emission vehicle

PFI vs. GDI -- No systematic changes in composition of organic gas emissions



PFI PM emissions going down



PFI PM emissions going down



GDI have higher PM emissions than PFI



GDI PM emissions dominated by Elemental Carbon (EC)



Differences in size distributions



Lowering GDI PM Emissions

- GDI engine design & calibration is still improving
 - Spray-guided GDI should reduce emissions

- Fuel reformulation
- Follow the diesel path: Gasoline particulate filters



Air

Plugs (trapped PM)

Fuel & soot (EC) formation processes



Hydrocarbon soot formation tendency:

Paraffins < isoparaffins < mono-olefins < naphthenes < alkynes <aromatics

Fuel effects on PM emissions: Particulate matter index (PMI)



VP(443K) = vapor pressure at 443K (170°C)



Particulate Matter Index (PMI) works (surprisingly) well for conventional fuels



VP(443K) = vapor pressure at 443K (170°C)

(Figure from Aikawa et al. SAE 2010-01-2115.)

Reducing aromatics in fuel generally reduces primary PM emissions

(John Farrell, HEI Fuel Aromatic Workshop 2016)

Ethanol and PM Emissions



(Butler et al., SAE Technical Paper 2015-01-1072)

Effects of gasoline particulate filter (GPF)



What about downwind of source?



Evolution of Gases and Organic Aerosol



Carnegie Mellon University

Secondary PM production exceed primary emissions



(Gordon et al. ACP 2014; Zhao et al. in prep)

Substantially less secondary PM production for alkylate fuel

Conclusions

Dramatic reductions in vehicle emissions over last four decades.

GDI vs. PFI:

• At tailpipe:

- Similar gaseous emissions
- GDI have higher PM emissions
- Strategies for controlling PM
 - Improved engine designs and operations
 - Fuel composition
 - Gasoline Particulate Filter

• Downwind:

- Similar secondary PM formation
- Secondary PM >> primary PM emissions from light duty gas vehicle (LDGV)

Important to control PM precursor emissions

Acknowledgments

- **CMU:** Yunliang Zhao, Rawad Saleh, Georges Saliba, Albert Presto, Tim Gordon, Ngoc Nguyen, Chris Hennigan, Andy May, Mrunmayi Karve, Shantanu Jathar, Yunliang Zhao, Neil Donahue, Peter Adams
- **ARB:** Alváro Gutierrez, William H. Robertson, Mang Zhang, Oliver Chang, Shiyan Chen, Pablo Cicero-Fernandez, Bruce Frodin, Mark Fuentes, Shiou-Mei Huang, Richard Ling, Jeff Long, Christine Maddox, John Massetti, Eileen McCauley, Kwangsam Na, Yanbo Pang, Paul Rieger, Todd Sax, Satya Sardar, Tin Truong, Thu Vo, Christopher Brandow, Lyman Dinkins, Richard Ong Antonio Miguel, Sulekha Chattopadhyay, Hector Maldonado, Bob Torres, Eileen McCauley

UC Berkeley: Allen Goldstein, Greg Drozd

Ford: Matti Maricq

Financial Support:

- ARB Contract #12-318 + Vehicle procurement, testing, and emissions characterization
- CRC A74/E96 CMU smog chamber experiments
- EPA STAR RD834554 CMU primary emissions measurements
- NSF graduate student fellowships

This presentation reflects the views of the authors and not any of the funding agencies. No official endorsement should be inferred.