Characterization of GDI PM during start-stop operation with alcohol fuel blends

Presenter: John Storey
Melanie DeBusk, Shean Huff, Sam Lewis, Faustine Li, John Thomas, and Mary Eibl

Oak Ridge National Laboratory

Effects of Fuel Composition on PM Health Effects Institute Workshop
Chicago, IL
December 8, 2016

Kevin Stork and Michael Weismiller
Fuel and Lubricant Technologies
Vehicle Technologies Office, DOE
**GDI Vehicle PM Emissions: Impact of cold start, fuels**

*Will start-stop technology impact GDI PM emissions? Does bio-fuel impact PM?*

- 2010, 2012: Observed high PM during cold start, ethanol reduced PM
- 2014: Detailed HC speciation showed changes in PAHs on PM

(SAE 2010-01-2129; 2012-01-0437; 2014-01-1606)
**GDI Vehicle PM Emissions: Impact of cold start, fuels**

**Will start-stop technology impact GDI PM emissions? Does bio-fuel impact PM?**

- 2010, 2012: Observed high PM during cold start, ethanol reduced PM
- 2014: Detailed HC speciation showed changes in PAHs on PM
  (SAE 2010-01-2129; 2012-01-0437; 2014-01-1606)

- 2014-2015: Obtained and evaluated 2014 Malibu e-Assist vehicle
- Bio-fuel may impact both fuel and lube contribution to PM
- Focus on Start-Stop effect on PM mass, soot and number
  - Tier 3 regulations will lower PM mass standard
  - PM soot ≈ black carbon, a potent contributor to climate change
  - Particle number is regulated in Europe currently
GDI Vehicle on ORNL’s Chassis Dynamometer

- 1 cold, 8 hot LA4’s each day
- LA4 = FTP Bags 1+2
- Start-stop begins on Hill 2
- PN, PM size with EEPS
- PM Soot with AVL Microsoot
- Zefluor filters for mass, chem

- 3 Cold Bag 1’s/filter X 2 filters
- 9 or 27 Bag 2 runs/filter

Tier 3 PM limit is 3 mg/mile

Fuels splash-blended:
- E0 = EEE Tier 2 cert
- E20 = EEE + 20% EtOH
- iBu12 = EEE + 12% i-BuOH
Cold start dominates mass for all three fuels - Filter Mass Measurements

- FTP Composite: weighted average of cold and hot
- Start-stop only increases hot cycle PM for isobutanol
Cold start dominates mass for all three fuels - Filter Mass Measurements

FTP Composite: weighted average of cold and hot
Start-stop only increases hot cycle PM for isobutanol
Soot emissions show similar trends to PM mass - Micro-Soot Sensor Measurements

- Soot emissions taken second-by-second
- Integrated over cycle and with exhaust flow to get mg/mile
- Wide variability in Hot, despite up to 27 runs
Soot emissions show similar trends to PM mass - Micro-Soot Sensor Measurements

- Soot emissions taken second-by-second
- Integrated over cycle and with exhaust flow to get mg/mile
- Wide variability in Hot, despite up to 27 runs

Cold Start

<table>
<thead>
<tr>
<th></th>
<th>E0</th>
<th>E20</th>
<th>iBu12</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Start Stop</td>
<td>7.5</td>
<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Stop Start</td>
<td>6.0</td>
<td>1.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Hot start

<table>
<thead>
<tr>
<th></th>
<th>E0</th>
<th>E20</th>
<th>iBu12</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Start Stop</td>
<td>0.5</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Stop Start</td>
<td>0.4</td>
<td>0.1</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Particle number emissions trend lower for Start-Stop - Engine Exhaust Particle Sizer Measurements

Cold Start

- EEPS Total Particle Number includes PM< 23 nm
- (#/cc) taken second-by-second (DR ~ 100)
- Integrated over cycle and with exhaust flow to get #/mile
Particle number emissions trend lower for Start-Stop - Engine Exhaust Particle Sizer Measurements

- EEPS Total Particle Number includes PM< 23 nm
- (#/cc) taken second-by-second (DR ~ 100)
- Integrated over cycle and with exhaust flow to get #/mile
### ANOVA (Analysis Of Variance)

#### Soot

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (E0, E20, IB12)</td>
<td>5.19</td>
<td>0.0072</td>
</tr>
<tr>
<td>Mode (SS, no SS)</td>
<td>19.18</td>
<td>0</td>
</tr>
<tr>
<td>Fuel * Mode</td>
<td>14.54</td>
<td>0</td>
</tr>
</tbody>
</table>

- Null hypothesis: there is no difference between fuels or start-stop modes
  - p < 0.05 means you reject the null hypothesis
  - p < 0.05 is statistically significant

#### Particle Number

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (E0, E20, IB12)</td>
<td>1.31</td>
<td>0.273</td>
</tr>
<tr>
<td>Mode (SS, no SS)</td>
<td>1.78</td>
<td>0.1837</td>
</tr>
<tr>
<td>Fuel * Mode</td>
<td>56.86</td>
<td>0</td>
</tr>
</tbody>
</table>

- For soot production, Fuel, Mode, and their interaction produced a significant difference in soot.
- For particle number, Fuel and Mode did not produce a significant effect. But their interaction did.
EEPS shows variability for same time intervals

- Variability between hot cycles observed (5 shown above)
- Wide bands, even with 9 cycles
- Data analysis ongoing to look at specific transients
EEPS maps relate size, number to soot production
Chemistry of GDI PM HCs
Collection and direct thermal desorption/pyrolysis of soot

- GDI PM collected from filter
  - Light suction on glass capillary
  - ~0.5 mg needed (70 or 90 mm)
- Transfer to pre-cleaned thimble
- TDP-GC-MS (2 chromatograms)
  - 1st Step Desorption to 325 °C
  - 2nd Step Pyrolysis direct to 500 °C
Does bio-fuel impact PM HCs?

- 2014: Collected soot under rich conditions with 3 fuels, E0, E30, iBu48
- Detailed HC speciation showed changes in PAHs on PM

(SAE 2014-01-1606)
Injection matters: Differences in adsorbed HCs apparent for two different platforms

So What?
Both engines: 2 L, GDI, $\lambda=0.9$
Difference:
- Side vs. Center injectors
- Different intake geometry

PAHs

Response normalized to 1 mg of soot

Time (min)

SAE 2012-01-0437
Start-Stop Study: E20 fuel has lowest measured PM and PAH

- FTP cold-hot weighted mass data for start-stop
- Ethanol appears to reduce PAH formation in the soot

Tier 3 PM limit is 3 mg/mile

![Graph showing PM mass emissions and PAH relative response](image)
Start-stop study: GC-MS didn’t detect lube HCs on filter

Lube HCs appear here as large peaks if present.
Summary: GDI vehicle PM depends on fuel and mode

- Lowest \textit{Cold} Start PM mass, soot and number = E20
- \textbf{Hot} start PM affected differently

<table>
<thead>
<tr>
<th></th>
<th>No Start-Stop</th>
<th>Start-Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM Mass</td>
<td>E0 ≈ E20</td>
<td>E20</td>
</tr>
<tr>
<td>Soot Mass</td>
<td>iBu12</td>
<td>E0</td>
</tr>
<tr>
<td>Particle #</td>
<td>iBu12</td>
<td>E0</td>
</tr>
</tbody>
</table>

- Largest particles contribute to soot emissions in first 300 s
- PAHs affected by alcohols
- Injection technology has improved both mass and chemistry
- “Uncontrolled” burns may be associated with PAH
- How about lubricant contribution?
  - Not conclusive, no lubricant found in PM organic fraction by GC-MS
- \textbf{Why is this research important?}
  - Start-up has highest PM emissions for GDI
  - Start-stop could impact particulate filter operation if GPF needed in 2025
- \textbf{Takeaway:} Operation and fuel both have to be considered for PM control strategies
Acknowledgements

• Kevin Stork and Michael Weismiller - DOE Vehicle Technologies Office, Fuel and Lubricant Technologies Program

• “This research was supported in part by an appointment to the Higher Education Research Experiences Program at Oak Ridge National Laboratory” (Faustine Li, Mary Eibl)

• Much helpful discussion with Matti Maricq, Imad Khalek, Dave Kittelson, Alla Zelenyuk

• Contact:
  John Storey
  storeyjm@ornl.gov
  865-946-1232