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

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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



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- 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







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



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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



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Cold Start

Hot start

- 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



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



Particle number emissions trend lower for Start-Stop - Engine Exhaust Particle Sizer Measurements



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- (#/cc) taken second-by-second (DR ~ 100)
- Integrated over cycle and with exhaust flow to get #/mile



ANOVA (Analysis Of Variance)

| Soot | F | р |
|-------------------------|-------|--------|
| Fuel (E0, E20, IB12) | 5.19 | 0.0072 |
| Mode (SS, no SS) | 19.18 | 0 |
| Fuel * Mode | 14.54 | 0 |

| Particle Number | F | р |
|-------------------------|-------|--------|
| Fuel (E0, E20, IB12) | 1.31 | 0.273 |
| Mode (SS, no SS) | 1.78 | 0.1837 |
| Fuel * Mode | 56.86 | 0 |

- Null hypothesis: there is no difference between fuels or startstop modes
 - p< 0.05 means you reject the null hypothesis
 - o p< 0.05 is statistically significant</p>
- 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



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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



GDI Vehicle PM Emissions: Impact of cold start, fuels

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



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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





Start-stop study: GC-MS didn't detect lube HCs on filter



Summary: GDI vehicle PM depends on fuel and mode

- Lowest Cold Start PM mass, soot and number = E20
- Hot start PM affected differently

| Lowest value: | No Start-Stop | Start-Stop |
|---------------|---------------|------------|
| PM Mass | E0 ≈ E20 | E20 |
| Soot Mass | iBu12 | EO |
| Particle # | iBu12 | EO |

- 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
- 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
- Takeaway: Operation and fuel both have to be considered for PM control strategies

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