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#### Black Carbon Particle Emissions from GDI Vehicles Operating on Different Fuels

Tak Chan

Emissions Research and Measurement Section, Air Quality Research Division, Environment Canada

Workshop on Effects of Fuel Composition on PM December 8, 2016 Renaissance Chicago O'Hare Suites (Salon AB), Chicago

## Studies exploring fuel effects on PM

#### Ambient air study

- Study conducted during a local diesel bus strike event
- Compare physical and chemical properties of ambient particles collected before, during, and after the strike
- Laboratory based emissions study
  - Particle emission characteristics from GDI and PFI vehicles
  - GDI PFI particle morphology
  - Ambient temperature effect on particle and black carbon emissions
  - Fuel composition on particle and black carbon emissions



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#### **Ambient particle measurements**



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#### Ambient air sampling



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#### **Ambient particle composition**



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NAP = Naphthalene ACY = Acenaphthylene ACE = Acenaphthene FLU = Fluorene PHEN = Phenanthrene ANTH = Anthracene FLT = Fluoranthene PYR = Pyrene BaA = Benzo[a]anthracene CHR = Chrysene BbF = Benzo[b]-fluoranthene BkF = Benzo[k]fluoranthene BaP = Benzo[a]pyrene IcdP = Indeno[1,2,3-cd]pyrene DBahA = Dibenz[a,h]anthracene BghiP = Benzo[ghi]perylene



Mass strike / Mass non-strike

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## Lab based particle sampling system



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## **PFI engine particle morphology**

MY2009 2.4L PFI engine operated on Tier 2 certification gasoline





TEM photos are shown in various resolutions for clarification

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## **GDI engine particle morphology**

MY2012 2.0L GDI vehicle operated on Tier 2 certification gasoline



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TEM photos are shown in various resolutions for clarification



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# **GDI engine particle morphology**

Cycle	<u>Stoc</u> DF	<u>k GDI</u> D (nm)
FTP-75 cold-start	1.8	88
FTP-75 urban	1.8	80
FTP-75 hot-start	1.7	85
US06	1.8	78





- GDI soot morphology is independent of the driving condition.
- GDI soot morphology is comparable to diesel soot morphology.
- Area-equivalent particle diameter is consistent with particle size distribution measurements.

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## **Fuel composition and properties**

Abbrev.	Description	Drive cycle tested
Tier 2	EPA Tier 2 certification gasoline	FTP-75, US06
Tier 2/E10	Splash blended 10%vol ethanol with Tier 2	FTP-75, US06
Tier 2/iB16	Splash blended 16%vol isobutanol with Tier 2	FTP-75, US06
Tier 2/E15	Splash blended 15%vol ethanol with Tier 2	FTP-75, US06
Tier 2/E20	Splash blended 20%vol ethanol with Tier 2	FTP-75, US06
Tier 3	EPA Tier 3 certification gasoline	FTP-75, US06

- Alcohol is not the only compound in fuel can influence particle emissions. Various hydrocarbons have different soot formation tendencies.
- Hydrocarbon soot formation tendency: Paraffins < isoparaffins < mono-olefins < naphthenes < alkynes <aromatics</li>





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### Fuels and solid particle emissions



- GDI vehicles have very different particle emissions characteristics compared to PFI vehicles.
- For GDI vehicles, particle number emission characteristics could vary from one vehicle to another.
- Effect of alcohol on particle number emissions from GDI and PFI vehicles is minor but varies greatly from one vehicle to the next.

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#### Fuels and black carbon emissions



- Black carbon emissions from GDI vehicles is much different compared to PFI vehicles.
- Variability in black carbon emissions from different GDI vehicles could be larger than from different PFI vehicles.
- Different splash blended alcohol containing fuels have minor influences on GDI than for PFI on black carbon emissions.

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## Ambient temp. impact on emissions



Ambient temperature (°C)

- Ambient temperature has a large impact on particle and black carbon emissions from both GDI and PFI vehicles. Impact is further enhanced during cold-start emissions.
- PFI vehicles could potentially have comparable black carbon emissions as GDI vehicles during cold temperature.

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## Size distributions from Tier 2 & 3



- Particle number size distributions generally look similar from vehicle GDI#2 but operating on Tier 2 produced slightly more particles.
- During aggressive driving condition significant number of ultrafine particles were emitted when operating on Tier 2. Slightly higher sulfur content from Tier 2 (37 ppm) vs. Tier 3 (8.4 ppm) could be one contributing factor.

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### PN & BC emissions from Tier 2 & 3



- For the GDI#2 test vehicle, operating on Tier 3 generally led to lower solid particle (>23 nm) emissions by 20-50%.
- Operating GDI#2 test vehicle on Tier 3 also led to lower black carbon emissions by 40-60%.

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### Conclusions

- Compositions of the combustion generated particles are influenced by engine types, vehicle fleet mix, gasoline composition.
- Black carbon particles from GDI vehicles appear to be different than that from traditional PFI vehicles.
- Ethanol and isobutanol could have mixed effects on particle number and black carbon emissions from GDI and PFI vehicles.
- Aromatic hydrocarbons in gasoline could play a role in black carbon formation from gasoline engines.
- Gasoline composition could have different effects on black carbon emissions from different vehicles.
- Vehicle operating condition could add another degree of complexity on black carbon emissions from a passenger car or light-duty truck (current work).



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#### **Research gap**

- Origin of the variability of the emissions from different vehicles:
  - With respect to GDI: Wall guided vs. spray guided
  - Advanced technologies on emissions: Engine start/stop, cylinder deactivation, hybrids, turbochargers
  - Octane level in gasoline on engine efficiency and particle formation
  - Real-world emissions
  - Non-road engines and equipment
- Understand the fuel composition effect:
  - Presence of various hydrocarbons in gasoline in relation to black carbon formation and emissions from vehicles
  - Vehicular emitted particle composition and fuel composition relationship
- Health effect:
  - Potential health effects of different exhaust emission particles



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