Gasoline Engines: Ultrafine Particle Emissions

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Outline

- Classifying vehicle exhaust particles
- How gasoline and diesel vehicle PM differs
- Real world emissions
- GDI versus PFI engines
- Gasoline PM at cold ambient temperatures
Underlying question: Vehicle emissions versus roadway PM?

Test cell data shows particle # to decrease with PM mass. So why is roadway dominated by nucleation mode?

PM versus engine technology

Roadway PM

Autobahn A4, Aachen Germany, with busy light and heavy duty traffic.

R. Vogt, V. Scheer, Ford Forschungszentrum Aachen
Differences between gasoline and diesel vehicle PM
Types of particles in vehicle exhaust

- **Soot mode**
  - Particles formed in cylinder
  - Mainly solid – soot, ash
  - Coagulation → log-normal mode at 50 – 100 nm
  - Fractal like shape
  - Electrically charged

- **Nucleation mode**
  - Super saturation of volatile material from dilution
  - Mainly liquid
  - Spherical
  - Sulfate & heavy hydrocarbons
  - Electrically neutral
PM formation: gasoline vs diesel

- Diesel engines
  - Combustion occurs at air - fuel interface
  - Soot ~proportional to fuel (other factors include EGR)
  - ~90% soot oxidizes during post flame mixing with air
- Gasoline engines
  - Premixed combustion
  - Stochiometric A/F \(\rightarrow\) almost no soot
  - Main source is transients, e.g. liquid fuel, loss of A/F
Size distributions for gasoline vehicle PM

- Size distributions are for transient PM emissions.
- They are constructed from FTP and US06 drive cycles.
- Emissions fall into the PM0.5 size range.
- No clear demarcation at either 100 nm (ultrafine) or 50 nm (nanoparticle)
“Real world” gasoline PM
Real world chasing of gasoline vehicle

- Measurements made on test track away from other vehicles.
- At 70 & 120 km/h neither soot nor nucleation mode is detected above background level.
- PM emissions during step accelerations also remain below background.

PFI gasoline vehicle
5 ppm S fuel, 14m, T=19C, RH=55%

Courtesy of V. Scheer and R. Vogt
Ford Forschungszentrum Aachen GmbH
Wind tunnel tests

- Current gasoline vehicle PM near ambient. Inset shows transients above ambient.
- Distinct nuclei mode not observed, even at high sulfur levels.
- Degradation of catalyst efficiency observed with high sulfur fuel.
Gasoline Direct Injection

Port fuel injection (PFI) – Fuel & air mix in intake port and are drawn into the engine cylinder during intake stroke.

GDI – Air drawn into cylinder during intake stroke. Fuel is injected separately either during intake or compression stroke.
Two modes of operation

- **Stratified**
  - Late fuel injection
  - Lean operation
  - Lower pumping losses
  - Fuel impingement, lack of mixing → higher PM

- **Homogeneous**
  - Early fuel injection
  - Stoichiometric A/F
  - Reduced emissions
Gasoline vehicle PM at cold temperatures (-7 C)
Gasoline PM at cold temperatures

- Temperature decrease from 25°C to -7°C → relatively large increase in gasoline (MPI) particle #
- Both solid and semi volatile # increase
- On absolute scale gasoline PM remains < 1/20 of diesel PM

Summary

- PM characteristics of modern PFI gasoline engines
  - Close A/F control $\rightarrow$ very low PM (often < 1 mg/mi)
  - PM predominantly a transient phenomenon
  - Particle # level tracks PM mass level relative to other engine technologies $\rightarrow$ no inordinate nucleation mode
  - Cold increases particle number, but from ~2% to 5% relative to light duty diesel

- PM characteristics of GDI
  - Stratified operation improves fuel economy, increases PM
  - PM during homogeneous operation is comparable to PFI gasoline vehicles
  - Most current development takes homogeneous approach
So, how to reconcile vehicle PM vs roadside?

- Data presented here are from modern, properly functioning, vehicles. The tight A/F control means that even small malfunctions could cause high relative increases in PM.
  - Oil leakage $\rightarrow$ heavy hydrocarbons that could nucleate
  - Faulty oxygen sensor $\rightarrow$ rich operation $\rightarrow$ higher soot formation

- Degraded catalyst performance – higher hydrocarbons could lead to increased nucleation

- Driving conditions with high use of transients, e.g., freeway entrance, could exacerbate PM emissions

- Dilution in test cell is with clean, low humidity air. Perhaps at the roadway there are synergistic nucleation opportunities, e.g., emissions from one vehicle exacerbating nucleation from the next.