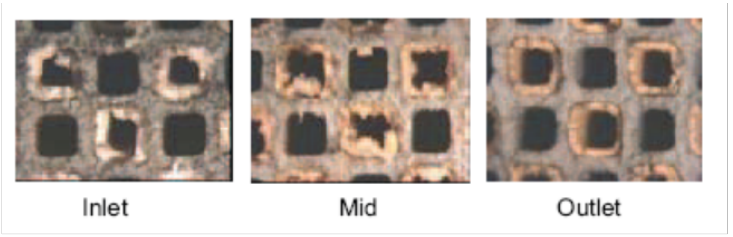
Ash particle emissions from a lean burn GDI engine

David Kittelson, Darrick Zarling, and Noah Bock

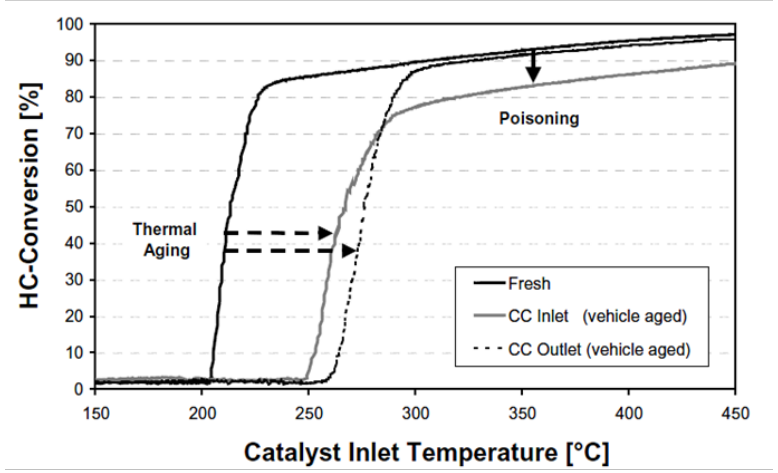
Center for Diesel Research
Department of Mechanical Engineering
University of Minnesota

Importance of ash emissions

- Diesel engines
  - Ash builds up
  - Increases pressure drop
  - Greater DPF cleaning frequency
  - Reduces useful DPF life
- Gasoline engines
  - Deposition in 3-way catalyst leads to poisoning
  - Solid nanoparticle emissions if GPF not used, especially with metallic additives
  - Ash can be good or bad in GDI engines
    - Ash membrane increases GPF efficiency
    - May enhance soot oxidation
    - But increases pressure drop
- Relationship to engine lube oil consumption mechanisms

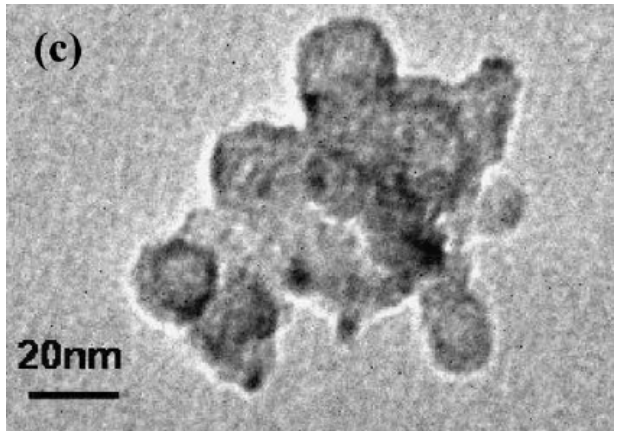


Ash distribution in exhaust filter channels (Heibel and Bhargava, 2007)

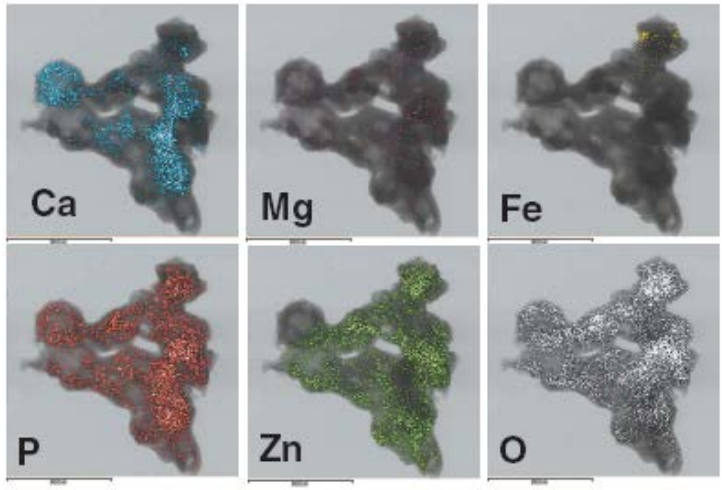


3-way catalyst poisoning by ash deposits (Franz, et al., 2005)

Engine ash emissions

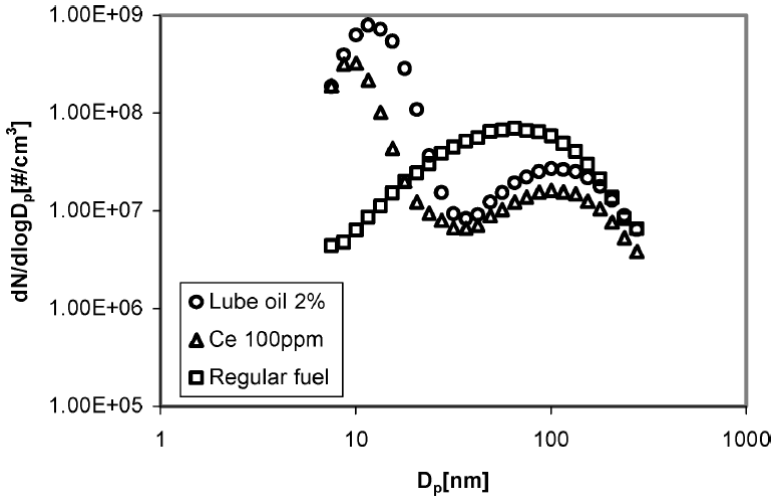


Jung, et al., 2005



Sappok and Wong, 2007

- Non-combustible fraction of diesel aerosol
- Derived from metallic lube oil additives and engine wear metals
- Metallic particles tend to ‘decorate’ carbonaceous exhaust particles
- But form separate particles at sufficiently high metal to soot ratios



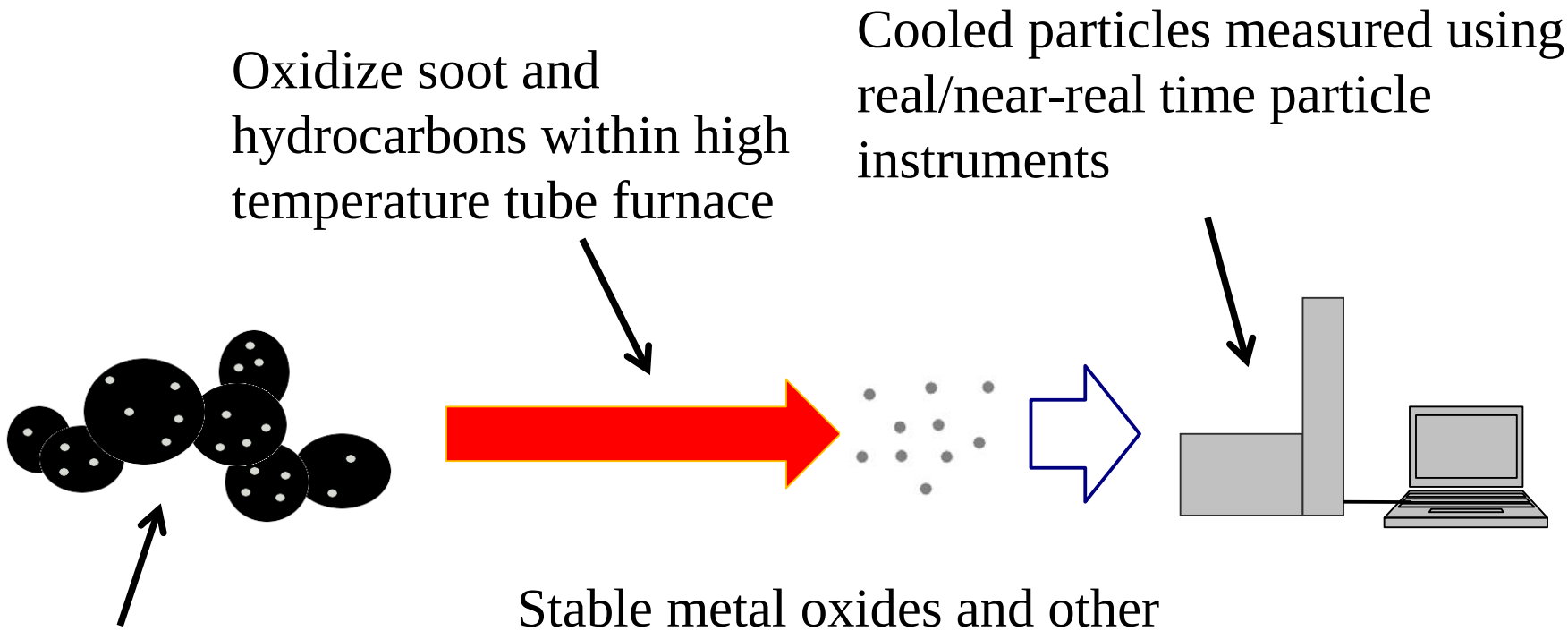
Jung and Kittelson, 2005

High temperature oxidation method (HTOM)

- Originally developed to study Diesel engine ash emissions in real time
- Allows oil consumption to be estimated – atomized but not vaporized oil – this material may contribute to sub 10 nm emissions
- Allows quick estimates of soot reactivity

- Current presentation
  - Brief review method
  - Example of application to Diesel
  - Impact of oil formulation on GDI engine soot reactivity and ash emissions

High temperature oxidation method (HTOM)

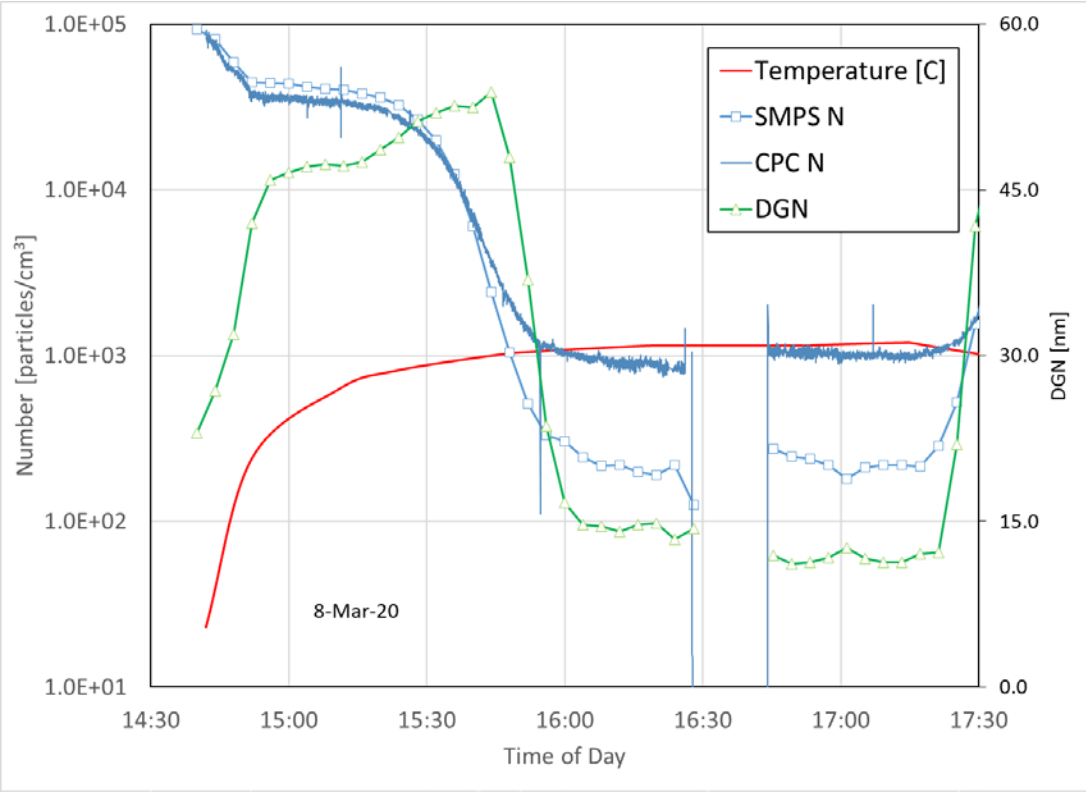


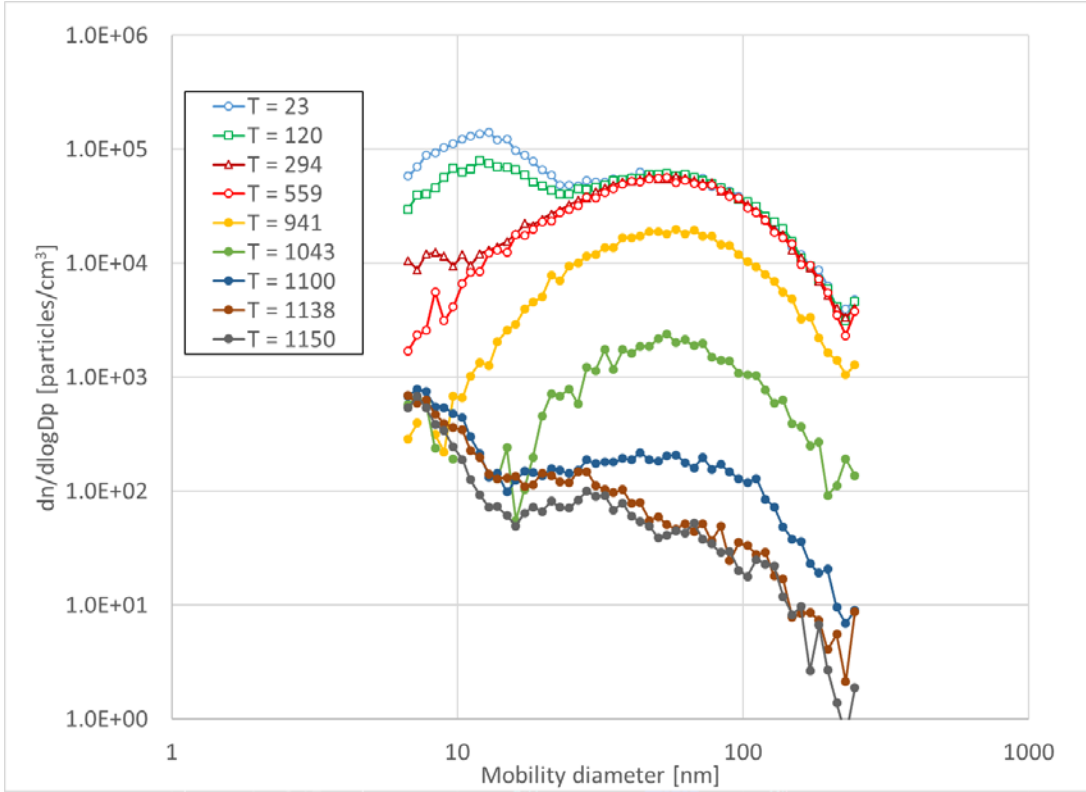
Gladis, 2010

Diesel examples

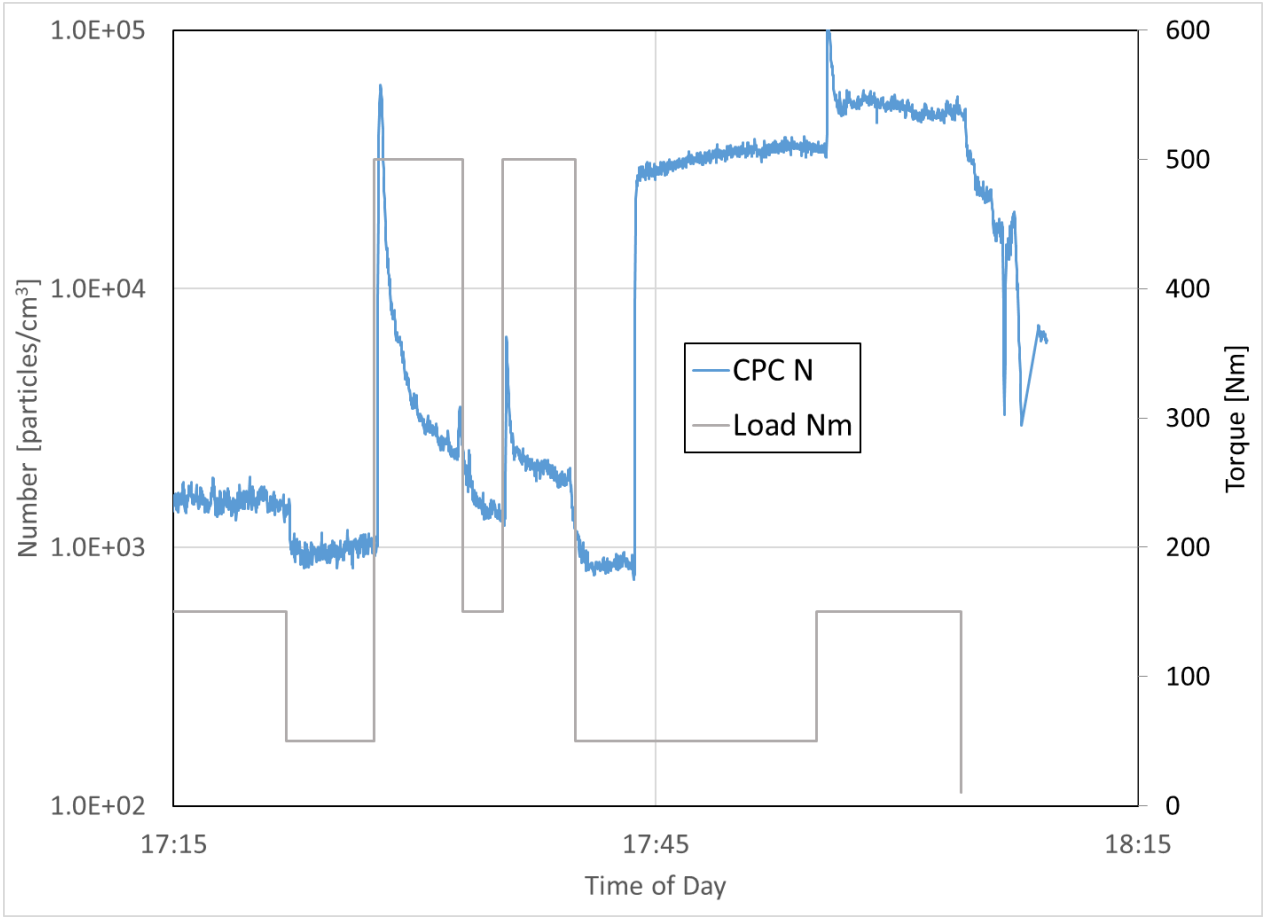
- Soot oxidation
- Transient ash emissions

Deere off-road tier IV engine
1400 rpm 50 N-m





Transient ash emissions – load steps at constant engine speed, Deere engine, 1500 rpm

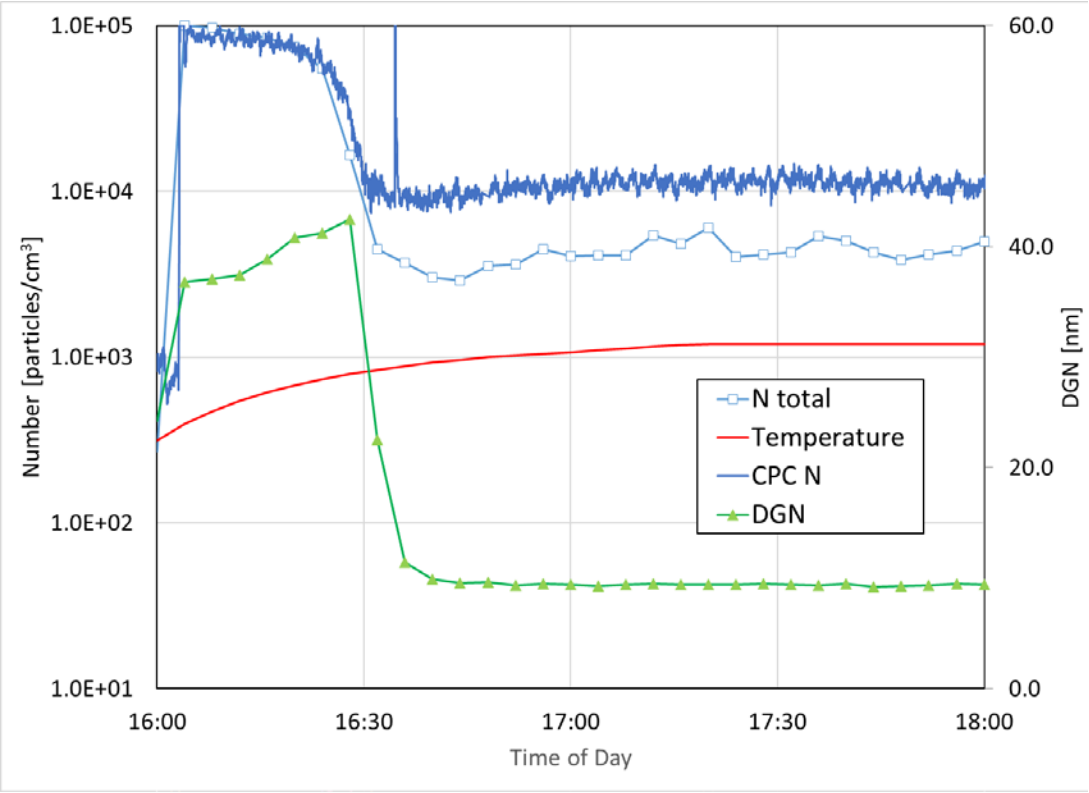


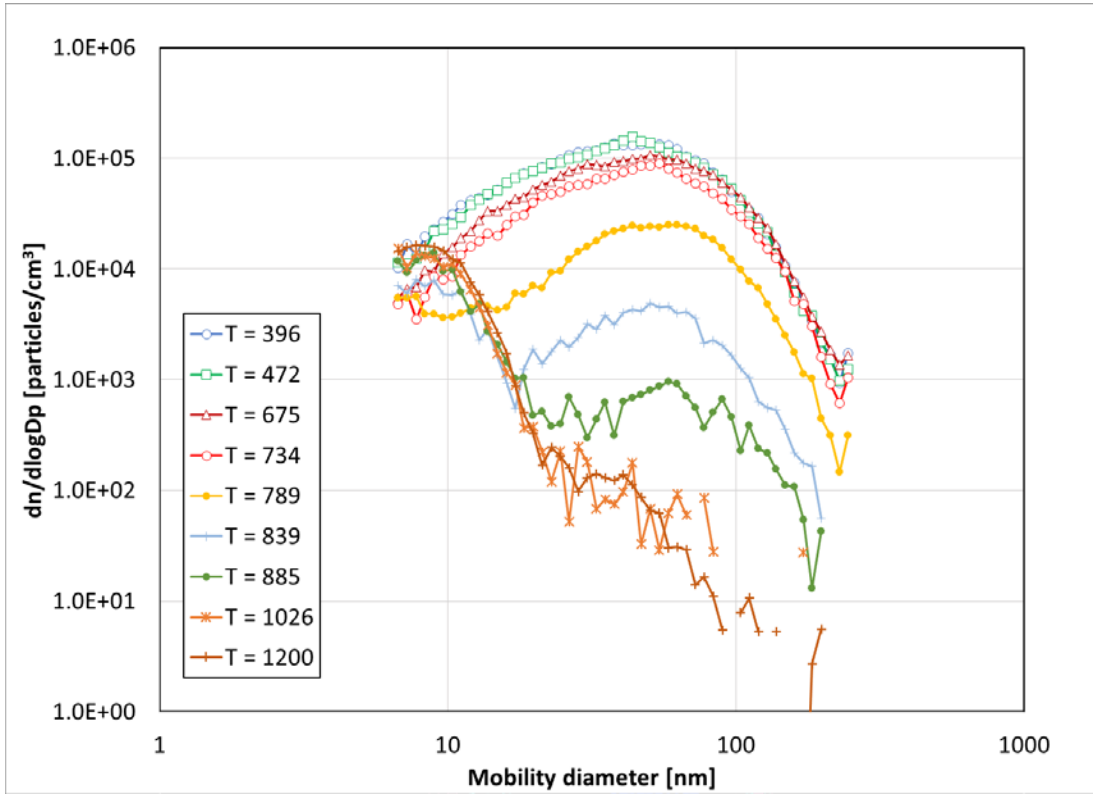
GDI engine tests

- N43B20, 2.0 L BMW GDI Engine – 4 cylinder naturally aspirated lean burn engine
- Constant speed and load: 2000 rpm, 6 bar BMEP, lambda = 1.2.

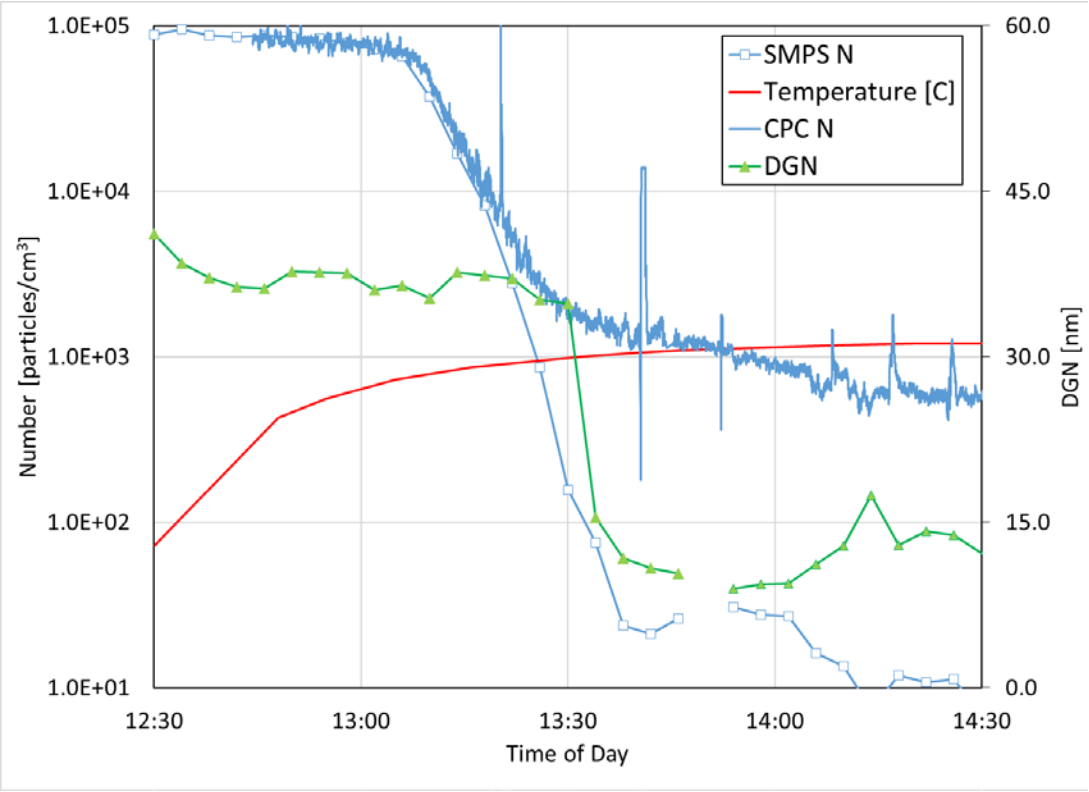
- Three lube oil additive packages
  - 5,000 ppm Ca
  - non-additized 100% PAO
  - 10,000 ppm ZDDP

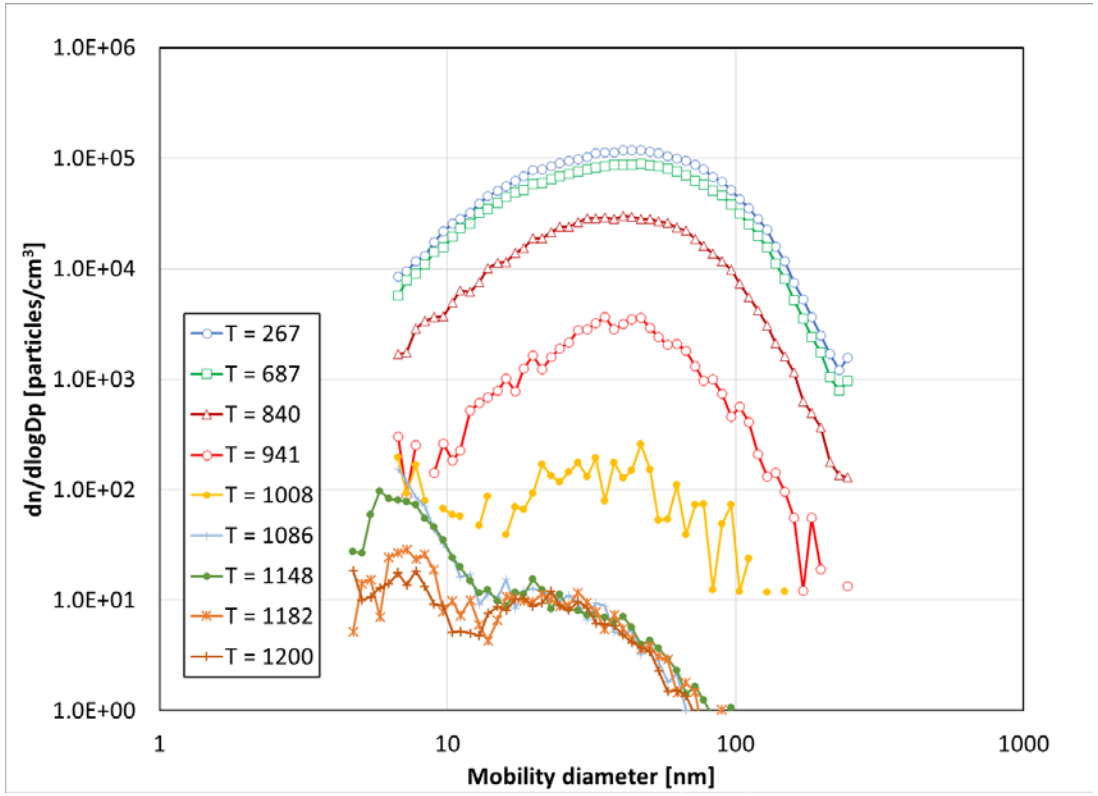
N43B20, 2.0 L BMW GDI Engine
Oil 1 – 5,000 ppm Ca



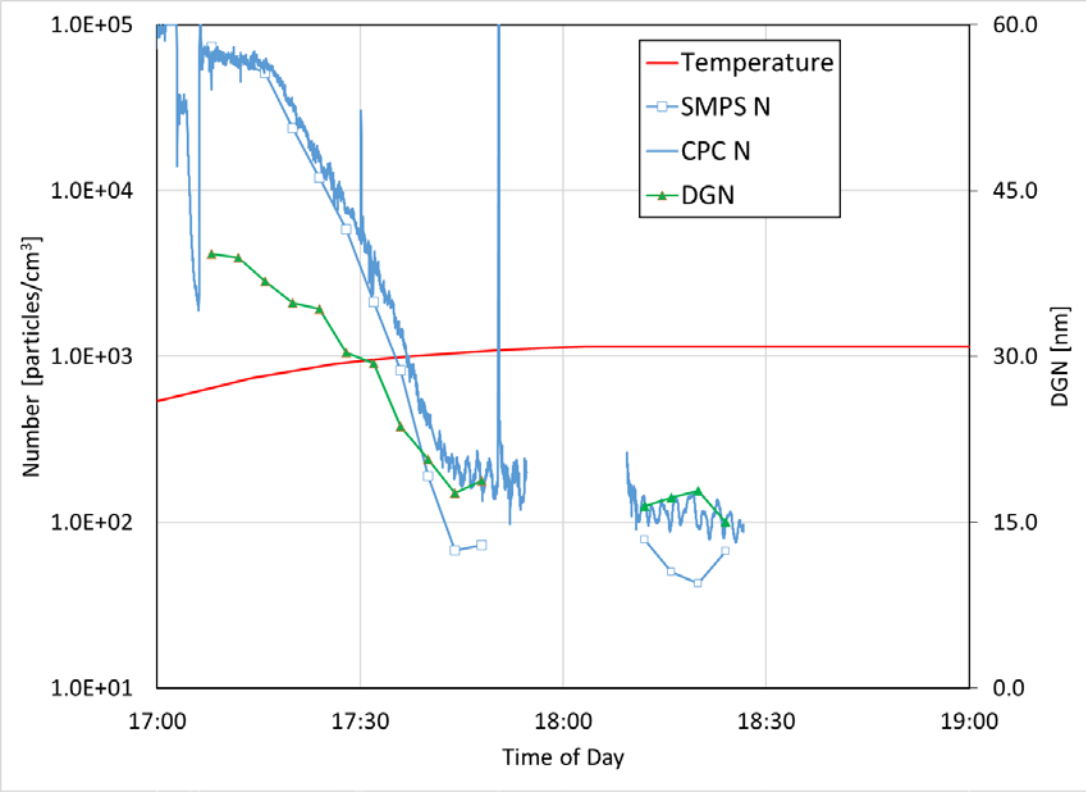


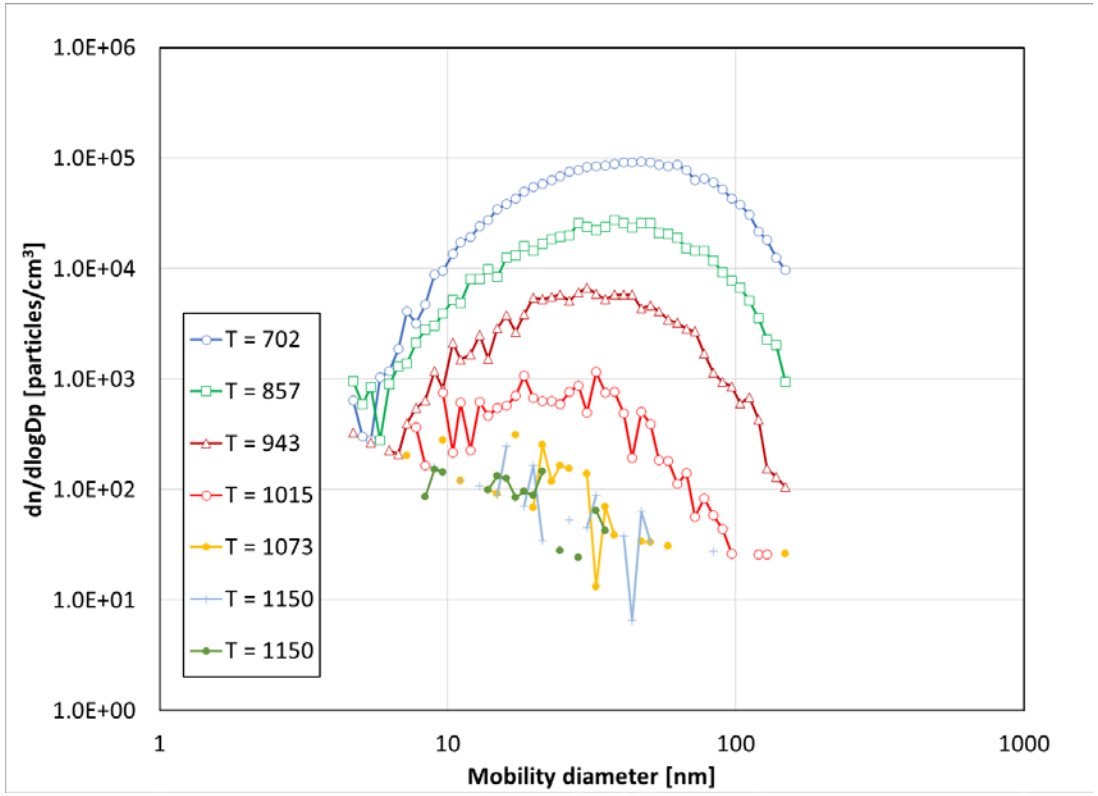
N43B20, 2.0 L BMW GDI Engine
Oil 2 – non-additized 100% PAO



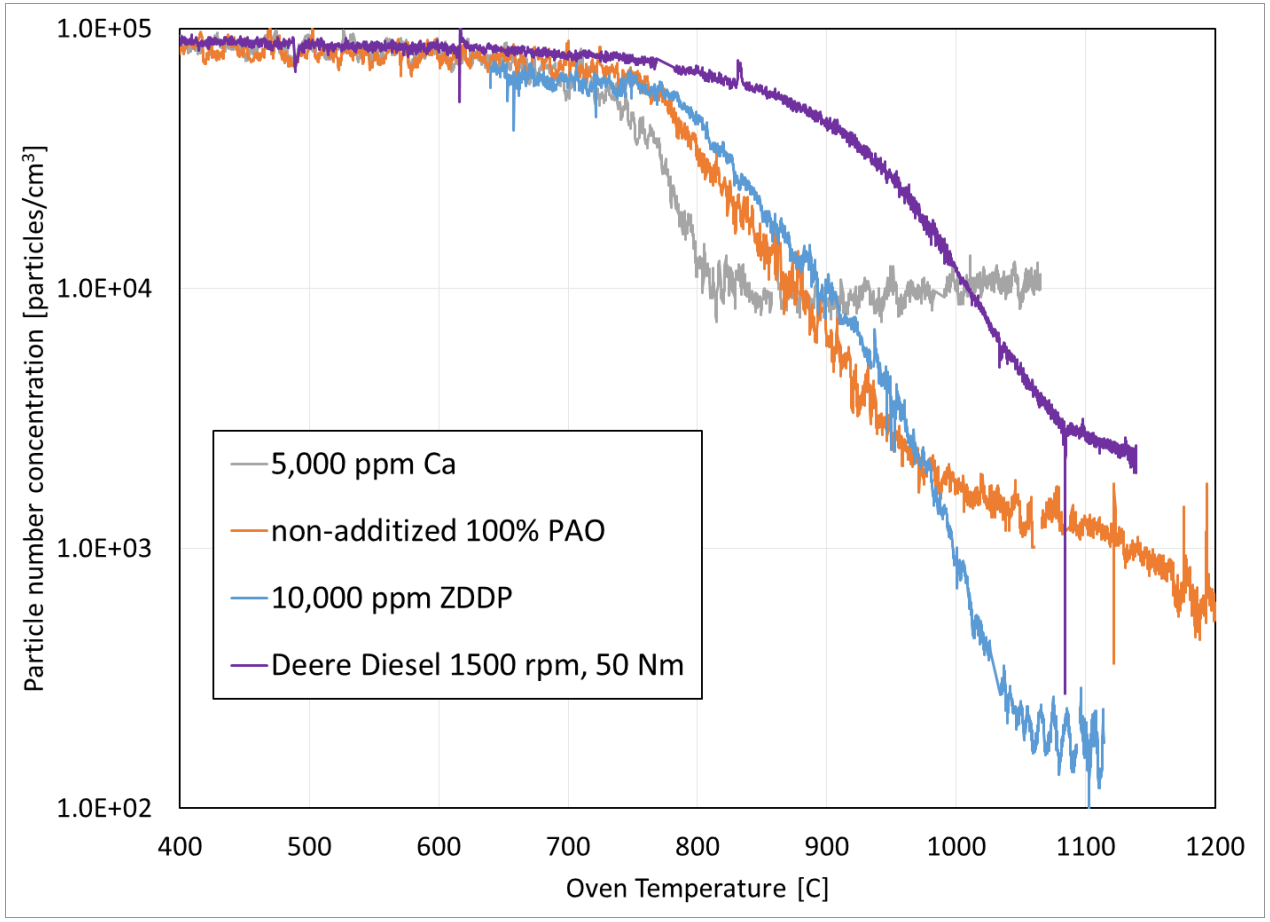


N43B20, 2.0 L BMW GDI Engine
Oil 3 – 10,000 ppm ZDDP





Soot Reactivity and Ash Fraction



Conclusions

- The high temperature oxidation method allows relatively simple assessments of soot reactivity and ash content

- Ash emissions - 5,000 ppm Ca > non-additized 100% PAO > 10,000 ppm ZDDP
- Soot reactivity - 5,000 ppm Ca > non-additized 100% PAO > 10,000 ppm ZDDP > Diesel