Semi-Volatile Nanoparticle Emissions From Diesel Low Temperature Combustion Modes

19th ETH Conference on Combustion Generated Nanoparticles
29.6.2015

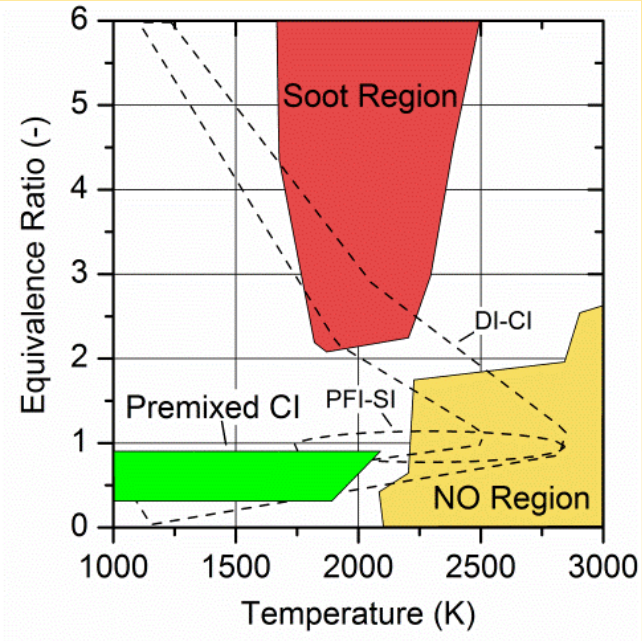
W. Northrop, G. Lucachick; Univ. Minnesota
S. Curran, J. Storey, V. Prikhodko; ORNL

UNIVERSITY OF MINNESOTA
Driven to Discover℠

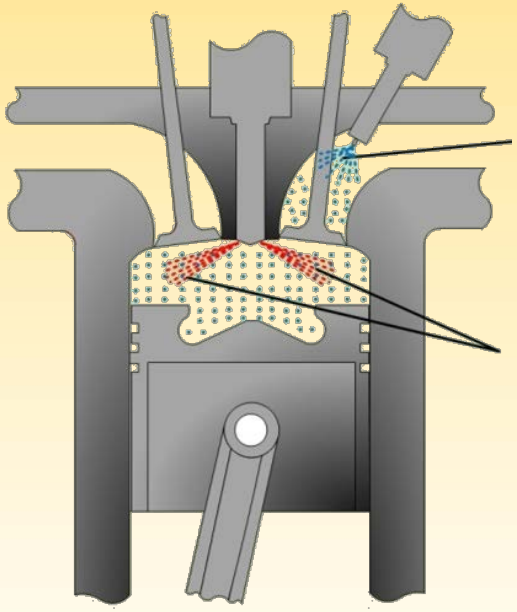
DEPARTMENT OF MECHANICAL ENGINEERING

Diesel Low Temperature Combustion

- **Advantages:**
  - Low soot and NO_X emissions
  - Reduced heat loss = higher efficiency
- **Disadvantages:**
  - Limited operating range
  - High HC/CO emissions

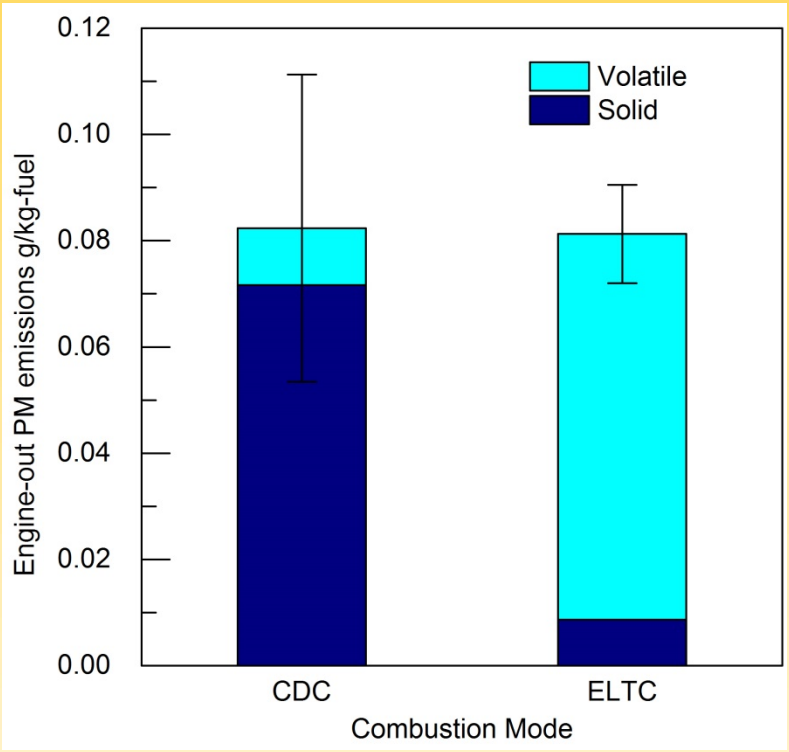


- Premixed Charge Comp. Ign. (PCCI)
  - Single fuel
- Reactivity Controlled Comp. Ign. (RCCI)
  - Dual fuel
  - Higher load capability



Particle Motivation

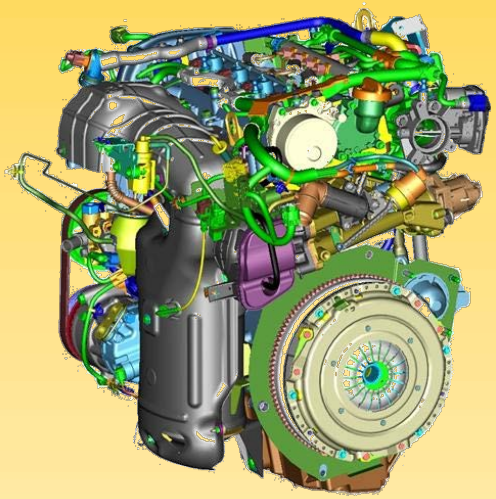
- Hypothesis:
  - Gas-to-particle conversion controlled by saturation ratio
  - At low engine exhaust temperature and high HC concentration, HC slip from aftertreatment
  - HC partial pressure in primary exhaust increases
  - Nucleation and growth of semi-volatiles occurs
- Semi-volatile particles regulated through mass standards in US
- Health effects being studied



Lucachick, G., et al. *SAE J. Engines* **7,** (2014).

Experimental Setup

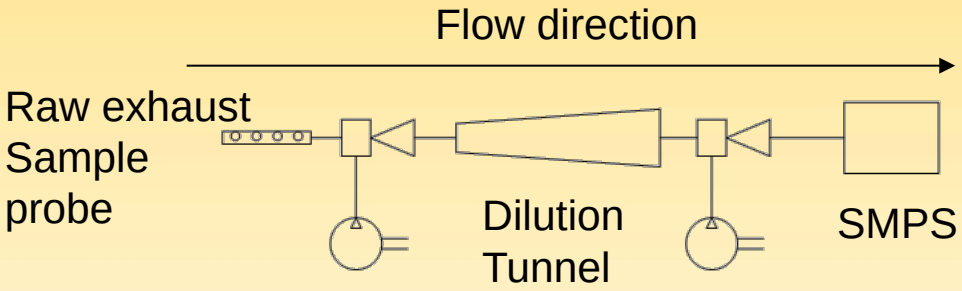
- Turbocharged DI-Diesel Engines
  - PCCI GM 2.0 liter EURO V
  - RCCI GM 1.9 liter EURO IV*
- Emissions Instruments
  - AVL i60 FTIR
  - AVL Microsoot
  - TSI SMPS
- Fuel
  - ULSD, non-oxygenated
  - Cert. gasoline, non-oxygenated



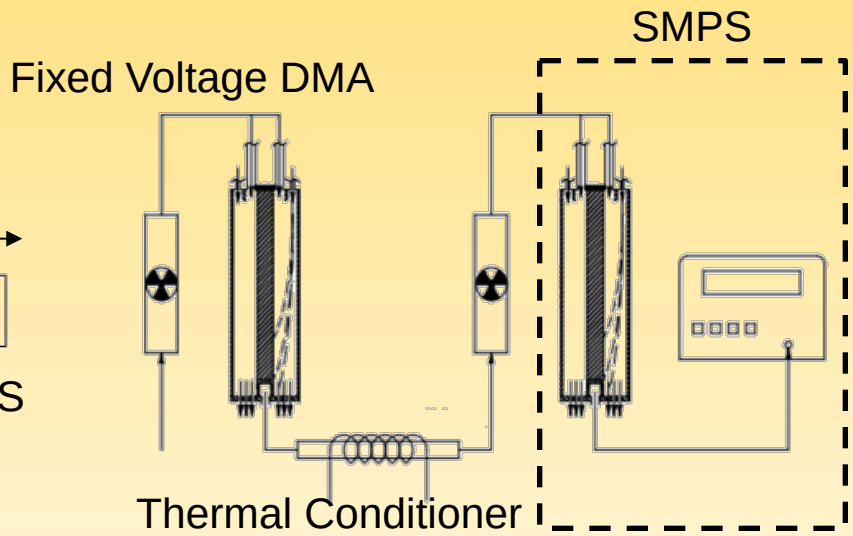
* Experiments conducted at ORNL

Particle Measurement

- Simulate primary dilution
- Understand particle volatility
- Catalytic stripper[1] – solid/volatile fraction
- Evaporative particle generator



Micro-Dilution System[2]

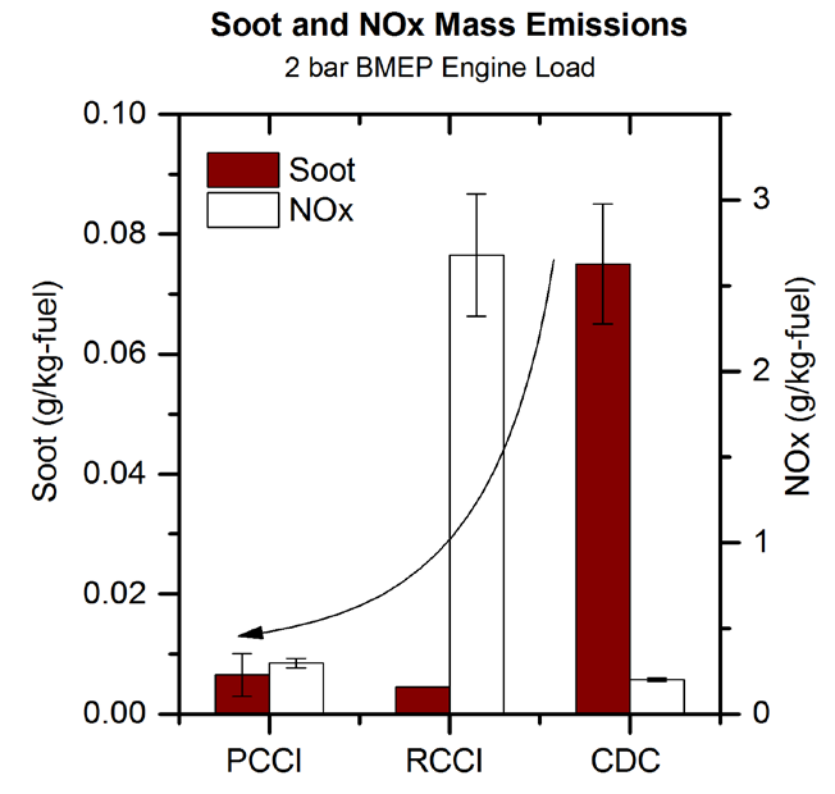


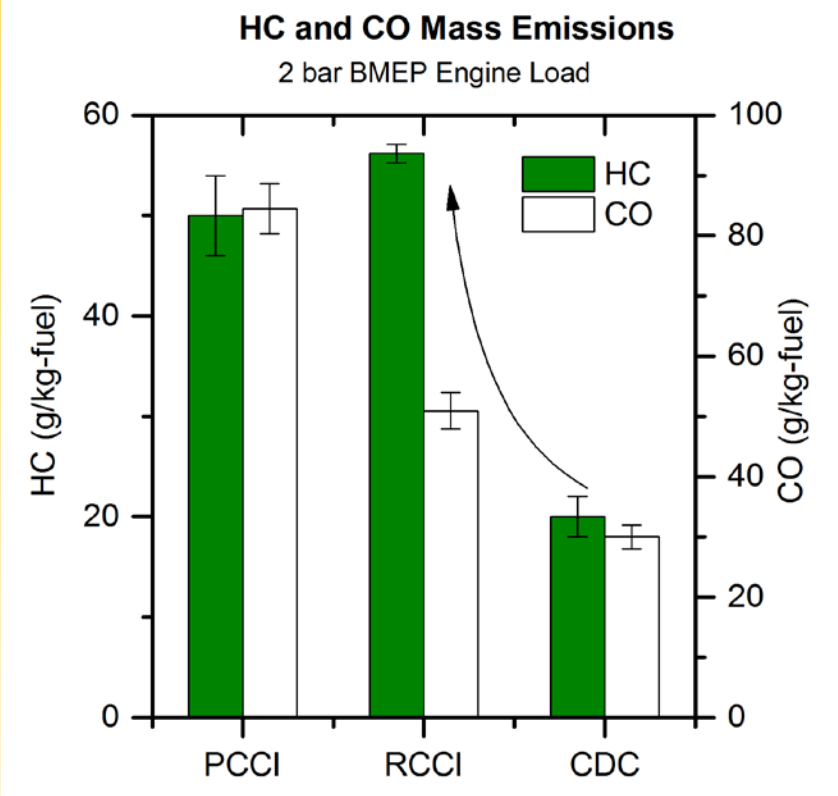
Tandem Differential Mobility Analyzer with Thermal Conditioning[3]

1. Abdul-Khalek, SAE Tech. Paper, 950236 (1995).
2. Abdul-Khalek, SAE Tech. Paper, 1999-01-1142 (1999).
3. Sakurai, et al. *Environ. Sci. Technol.* **37,** 5487–5495 (2003).

Comparison of LTC and CDC Emissions

Engine-Out Results



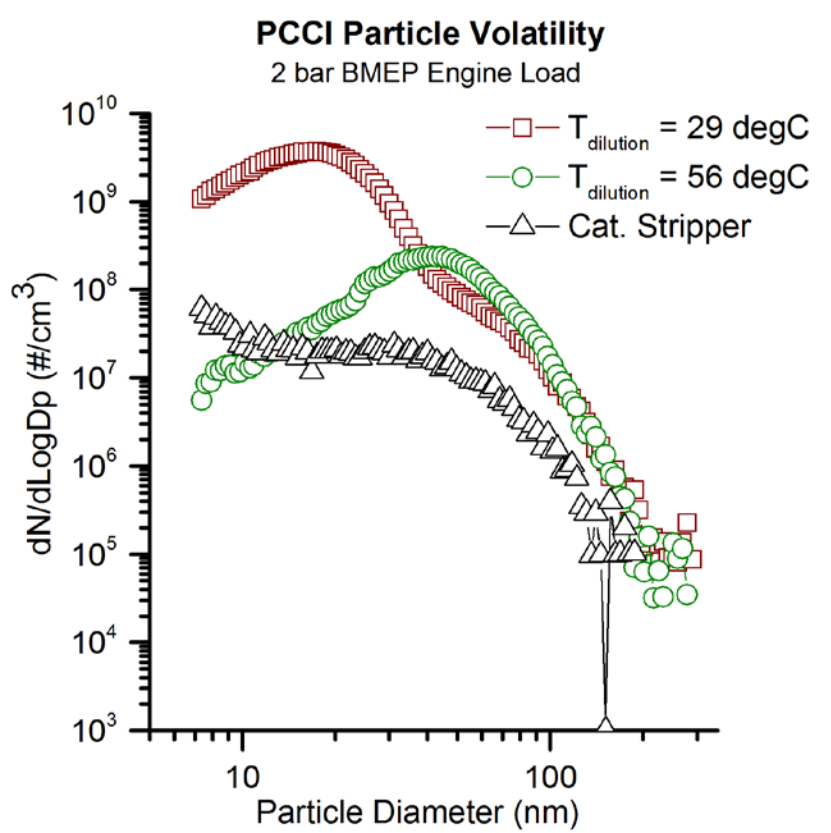


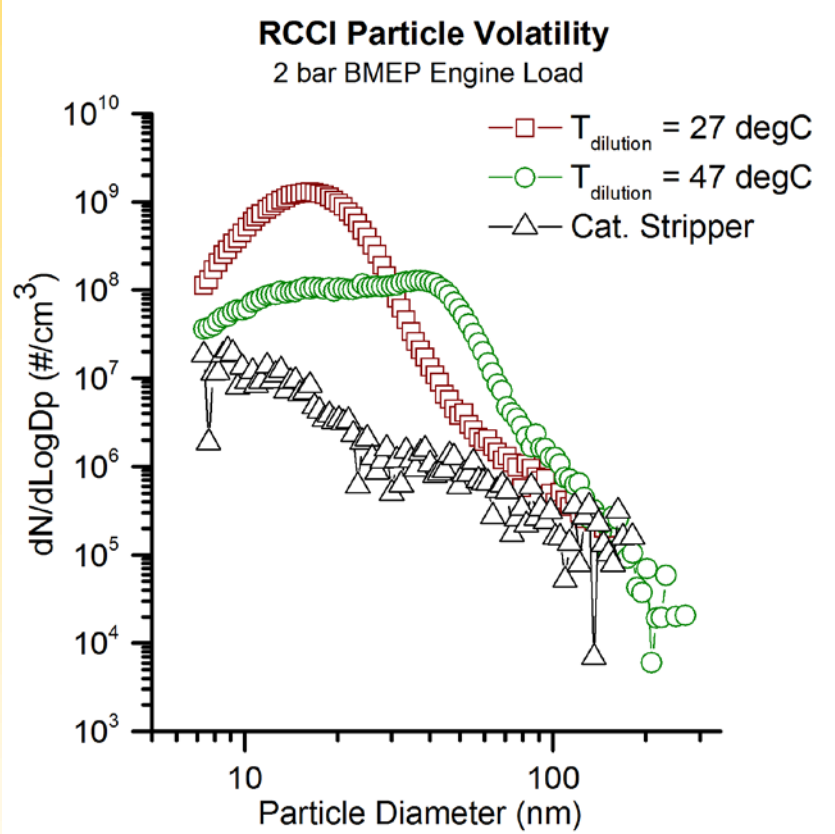
- LTC lowers soot mass emissions…

…but increases HC Emissions

LTC particles highly sensitive to dilution temperature

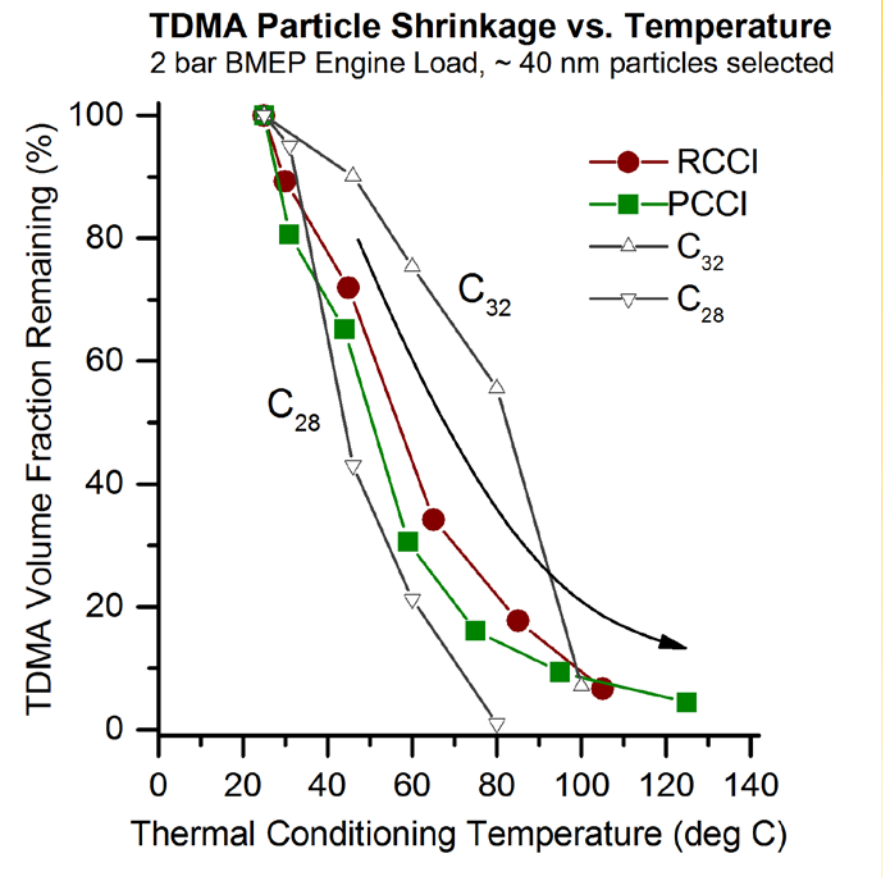
- RCCI and PCCI particles – similar volatility
- Particle number decreases with $T_{dilution}$





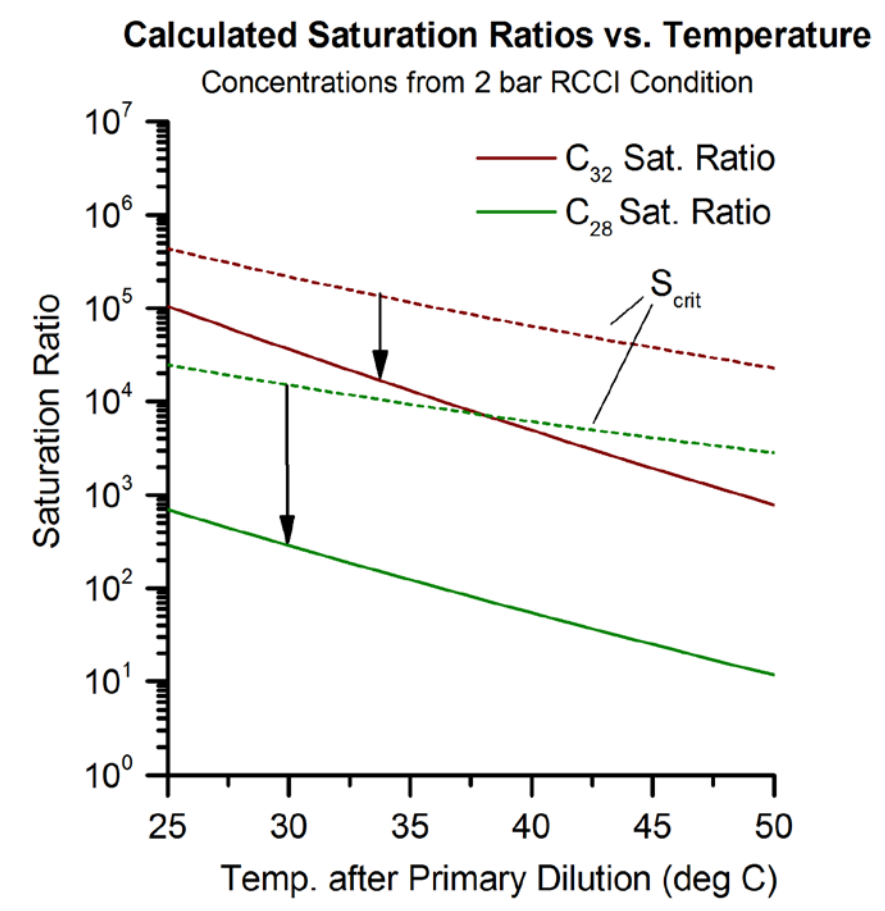
LTC particles have similar volatility range to C_{28} – C_{32} alkanes

- Evaporative TDMA
  - 40 nm particles
  - $T_{dilution}$ = 27 deg C
- Compared to evaporative particle generator
  - Alkanes similar to lube oil
  - Engine particles consist of many species
  - Decreasing volatility with size



Saturation Ratio Implies LTC Particles Unlikely to Nucleate Homogeneously

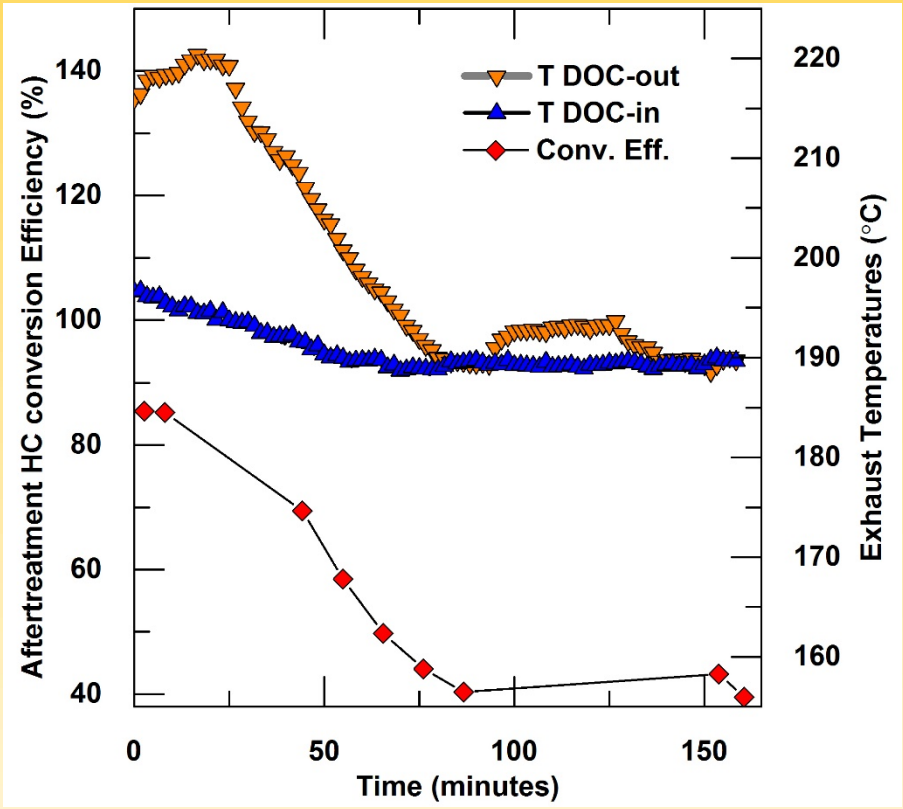
- Saturation ratios estimated[1]
  - Consist of pure alkanes
  - Particle volume from experimental RCCI condition
- Critical saturation ratios[2]
- Further evidence of low volatility small particles
  - Sulfate nuclei
  - Non-volatile oxygenates



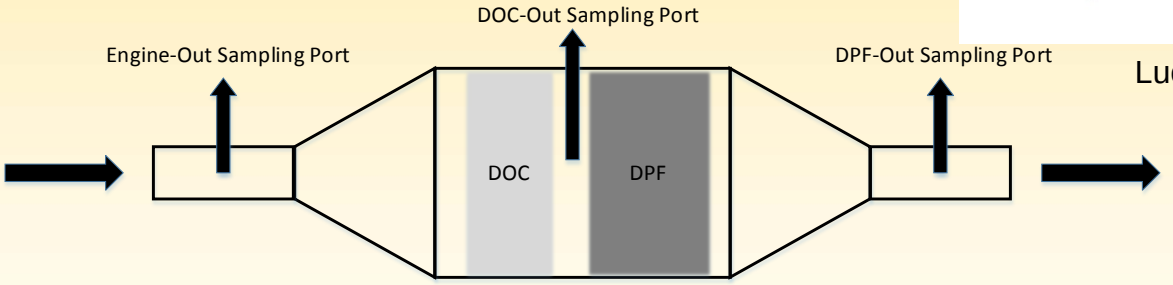
1. Chickos, J. S., & Hanshaw, W. (2004). J. of Chem. & Eng. Data, 49(1), 77-85.
2. Rusyniak, M., et al. (2001). Vapor phase homogeneous nucleation of higher alkanes: dodecane, hexadecane, and octadecane. 1. Critical supersaturation and nucleation rate measurements. J. Phys. Chem. B, 105(47), 11866-11872.

DOC catalyst deactivates over a long period running in LTC mode

- EURO V aftertreatment
  - Close-coupled DOC-DPF
- Test performed after DPF regeneration
  - 2 bar BMEP PCCI Condition
  - HCs from DOC should form particles after dilution



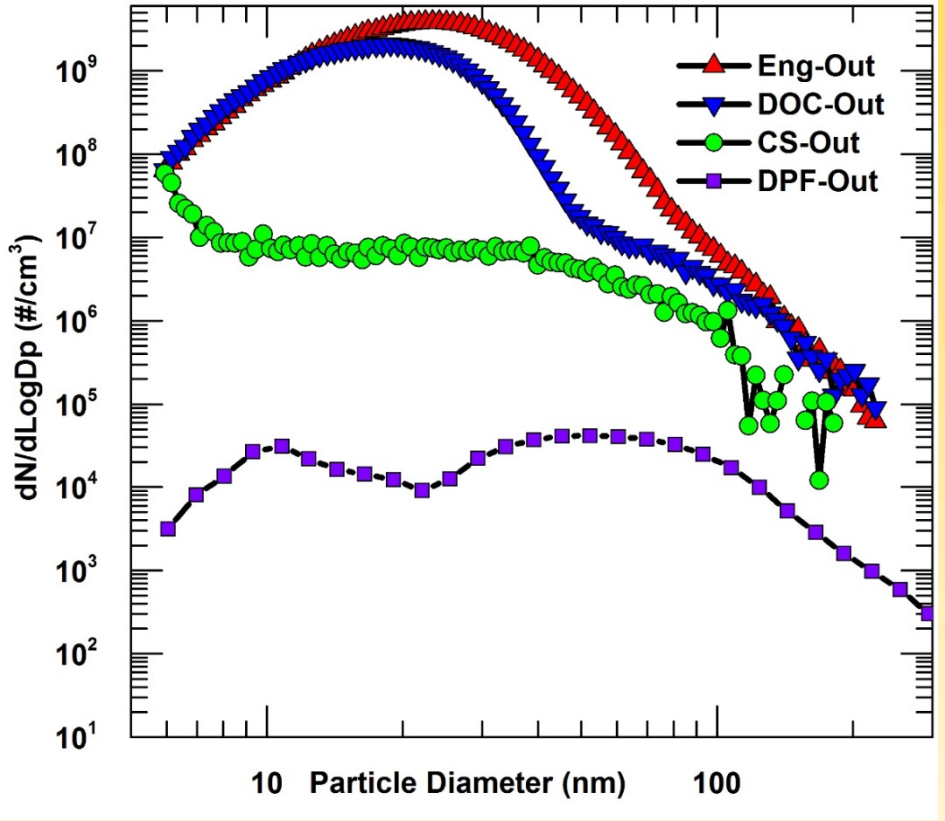
Lucachick, et al. *SAE J. Engines* **7,** (2015).



Aftertreatment eliminates >99% of LTC particles even with DOC partially deactivated

- Time = 100 s after regen.
- DOC not fully operational
- DPF very effective
  - Adsorption on filter/soot cake
  - Removal of nucleation sites

Sampling Location	Temperature (° C)
Engine-Out	189
DOC-Out	192
DPF-Out	NA
Catalytic Stripper	350



Lucachick, G., et al. *SAE J. Engines* **7,** (2015).

Summary

- PM from LTC is mostly semi-volatile
  - Highly dependent on dilution conditions
- Dual fuel RCCI and single fuel PCCI modes have largely similar particle size distributions and dilution sensitivity
- Semi-volatiles not predicted to nucleate homogeneously
  - Gas to particle conversion on highly non-volatile species
- LTC modes still require aftertreatment
- DPF effectively prohibits semi-volatile particles
  - Either from adsorption of HC or nucleation site removal
  - New conditions with DPF slip being explored

Questions?

Funding Acknowledgement: Research Gift from General Motors and University of Minnesota

Contact:
W. Northrop
University of Minnesota
wnorthro@umn.edu