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Particle Emissions and Soot Reactivity using Renewable Fuels in a Diesel Engine

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Introduction

Renewable fuels are important to avoid fossil (global) CO_2 emissions and can be used as "drop-in" fuels (same fuel standard). The performance of renewable fuels are similar to diesel regarding fuel consumption and gaseous emissions [1].

Particulate Matter (PM) (local) emissions cause serious health problems. Diesel Particulate Filters (DPF) have high capture efficiencies but the performance depends on the combustion characteristics.

The understanding of Particle Size Distribution (PSD) and soot reactivity are important for successful future implementation of renewable fuels.

Engine experiments [1]

- 1-cylinder heavy-duty diesel engine (2 dm³)
- 2 different fuels:
  - Diesel fuel: (CN = 52, 0 % Oxygen)
  - Bioblend (CN = 52.4, 4.6 % (w/w) Oxygen)
    - 46 vol-% 2-Propyl-hexanol
    - 34 vol-% HVO
    - 20 vol-% diesel Fuel

PM emissions measurements

- DMS 500 (from Cambustion), sampling after catalytic stripper
  - Removing volatile components [3]
  - Mimicking real EATS application

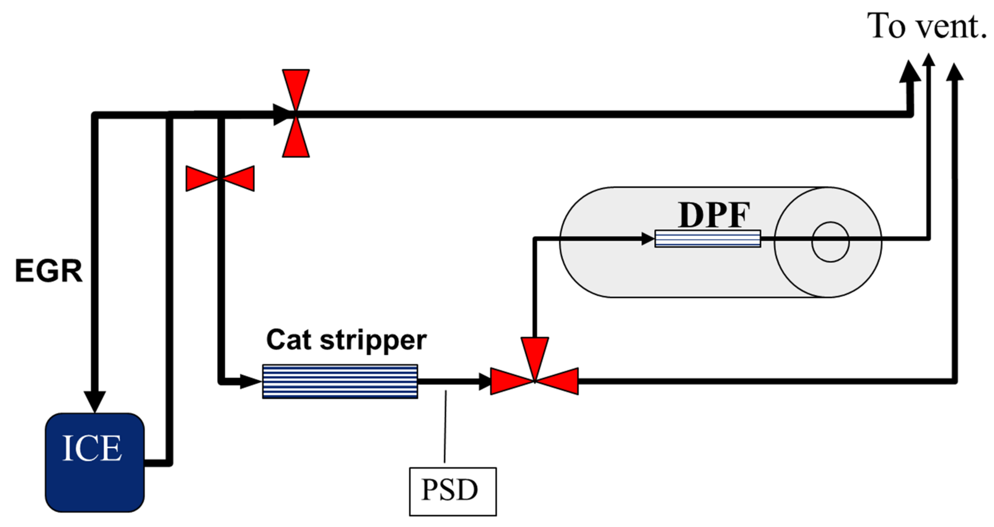

Figure 1. Schematic of the powertrain setup

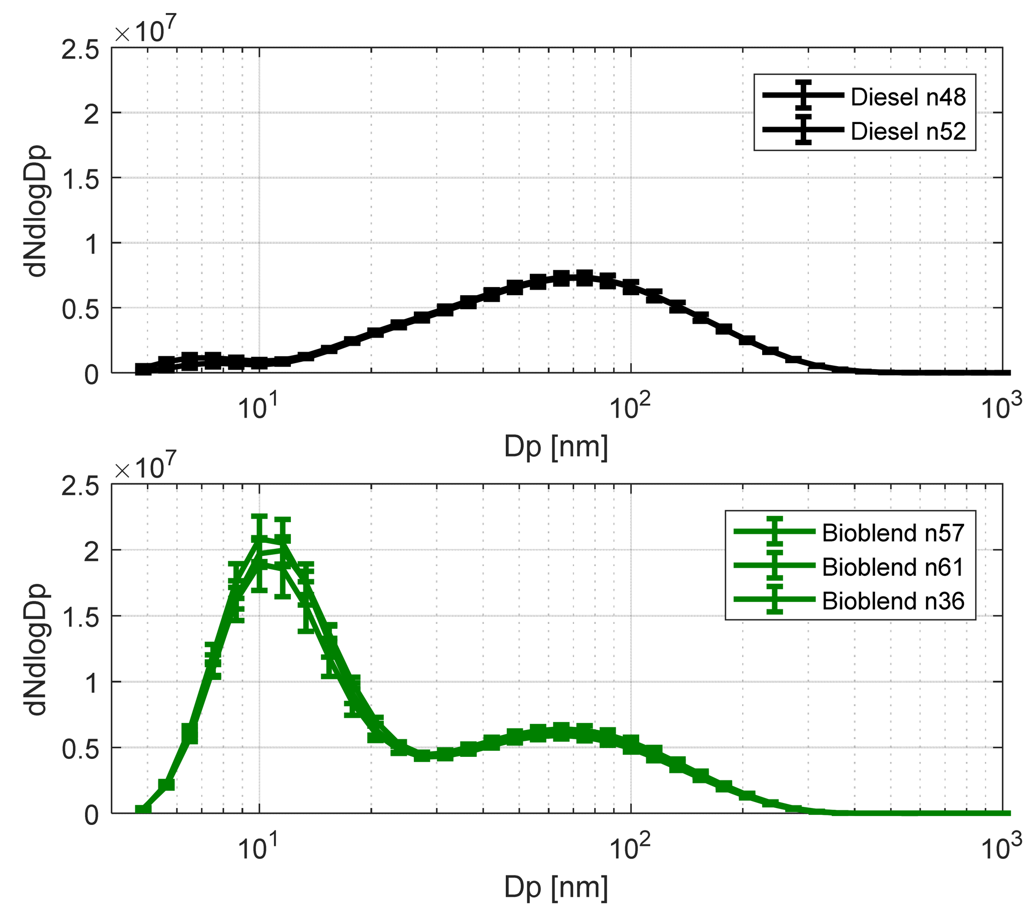

Figure 3. Particle Size Distribution (PSD) comparing the two fuels. 1st dilution = 3, 2nd dilution (rotating disc) = 12, sampling time: 30-60 sec, repeated 2-3 times

PSD results

- Similar amount of accumulation mode
- Bioblend generated more (and larger) nucleation mode PM
- Nucleation mode is not volatile (since passing through a catalytic stripper) [3]

Objectives

- To compare the PM emissions from diesel fuel and renewable fuels.
- To investigate differences in soot reactivity.
- To bridge between full scale and lab scale experimentation [2].

Soot loading and kinetic experiments

- Mini-DPF 6" x 0.5" (L x D), 200 cpsi, SiC/CeO_2
- Loading at 350 °C, 8-10 g/dm³
- Oxidation using pulse experiments at steady temperatures
  - T = 400 – 600 °C
  - $[O_2]$ = 1000, 4000 ppm, $[NO_2]$ = 0, 400 ppm
- Simple kinetic analysis assuming global reaction rate ("shrinking core"):

$$r_i = A_i \exp(-Ea/RT)[O_2]^{0.8} m_0 (1-X)^{2/3}$$

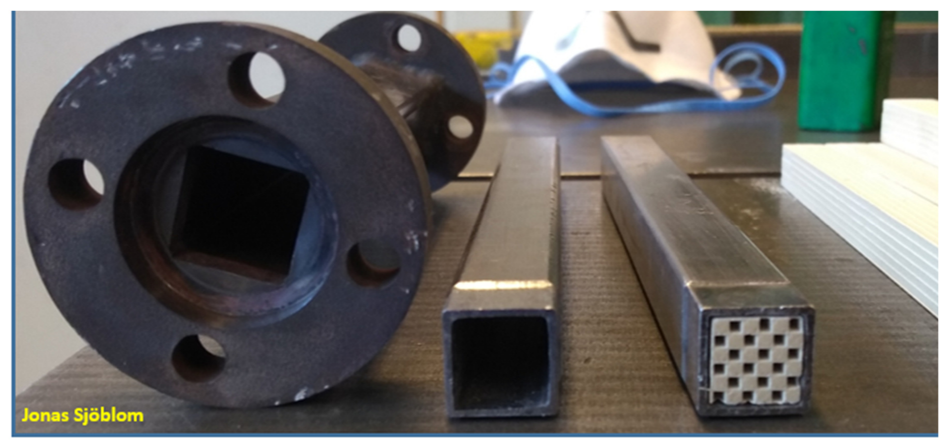

Figure 5. Photo of the mini-DPF reactor and DPF-cartridge

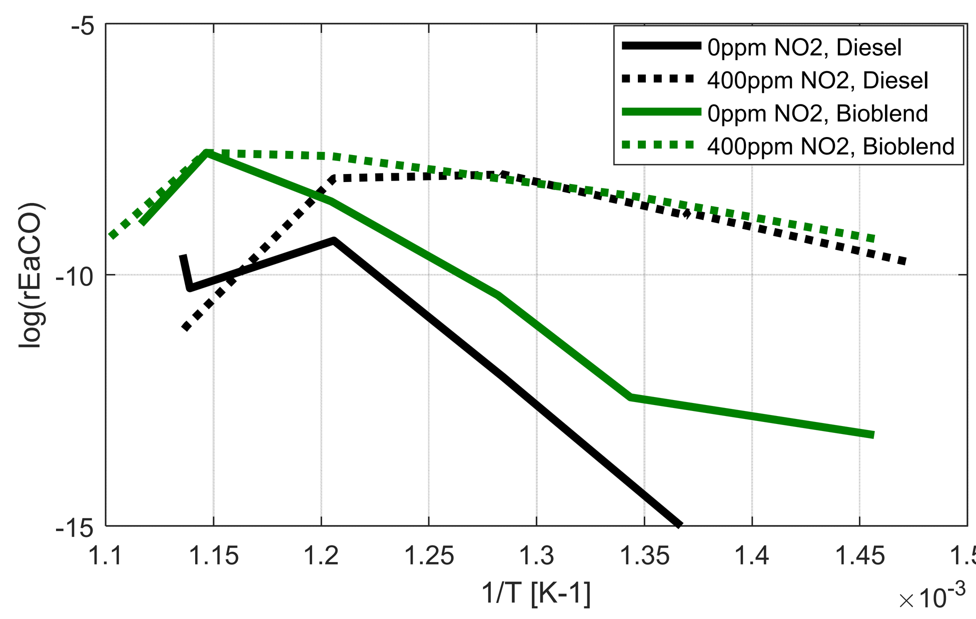

Figure 6. Arrhenius plots for CO formation at $[O_2]$ = 4000ppm. (At high temperatures mass transfer and thermal equilibrium effect becomes important.)

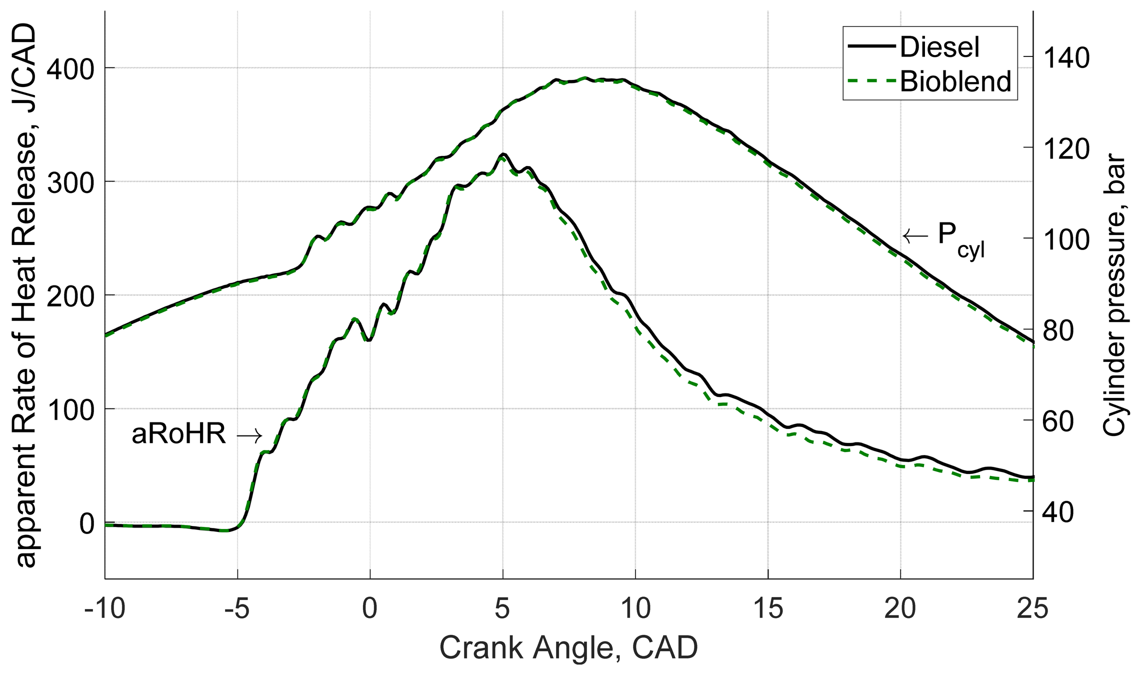

Figure 2. Cylinder Pressure and RoHR. Medium Load (1500 rpm, 160 Nm) Single injection (SOI=7.8 CADbTDC, Pinj=1800bar), EGR = 12.9 %, lambda = 2.05

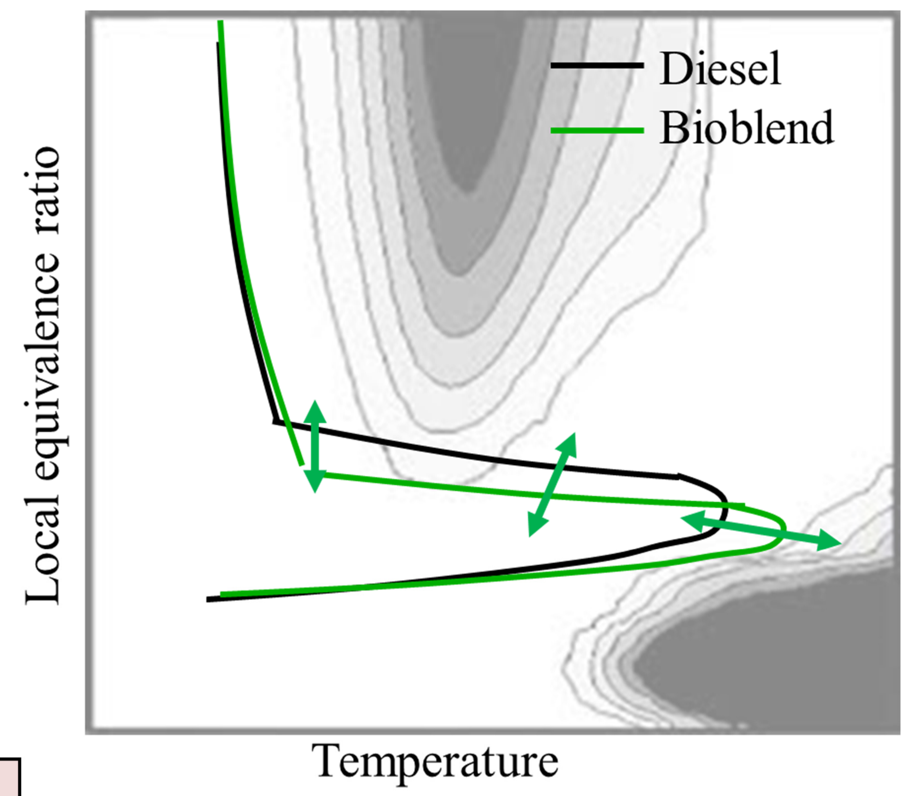

Figure 4. Conceptual model for soot and NO_X formation in a diesel engine.

Soot reactivity results

- NO_2 assisted oxidation: similar reactivity
- O_2-only oxidation:
  - Similar activation energy (Ea, slope)
  - Higher reactivity for bioblend (smaller particles, more reactive surface)
- Selectivity (CO/CO_2) was similar (not shown)

Engine results

- Very similar combustion (Apparent Rate of Heat Release) and gaseous emissions (slightly lower CO emissions) [1]
- Lower soot emissions for the Bioblend [1]

Discussion &Conclusions

- Bioblend generates smaller PM compared to diesel fuel
  - Although not completely understood yet, the reasons may include: physical properties (mixing), chemical properties (soot pre-cursors and in-cylinder oxidation and/or flame-cylinder wall interactions
- Smaller PSD from bioblend generates higher reactivity, due to larger reactive surface
  - PM properties are important for future efficient emission control.

References
[1] Preuß, J., K. Munch, and I. Denbratt, "Performance and emissions of long-chain alcohols as drop-in fuels for heavy duty compression ignition engines". Fuel, 2018. 216: p. 890-897.
[1] Sjöblom, J. (2013). "Bridging the gap between lab scale and full scale catalysis experimentation." Topics in Catalysis 56(1-8): 287-292.
[2] Sjöblom, J. and H. Ström (2013). "Capture of automotive particulate matter in open substrates." Industrial & Engineering Chemical Research 52(25): 8373–8385.