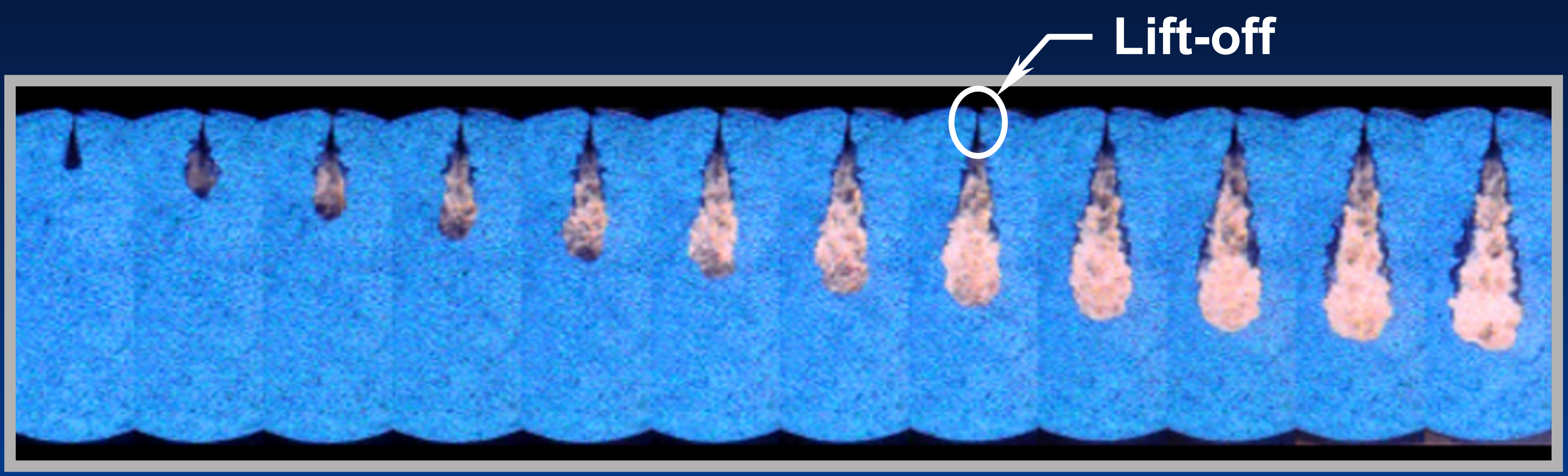
Soot in Direct-Injection Diesel Fuel Jets



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Sponsors: DOE/OFCVT
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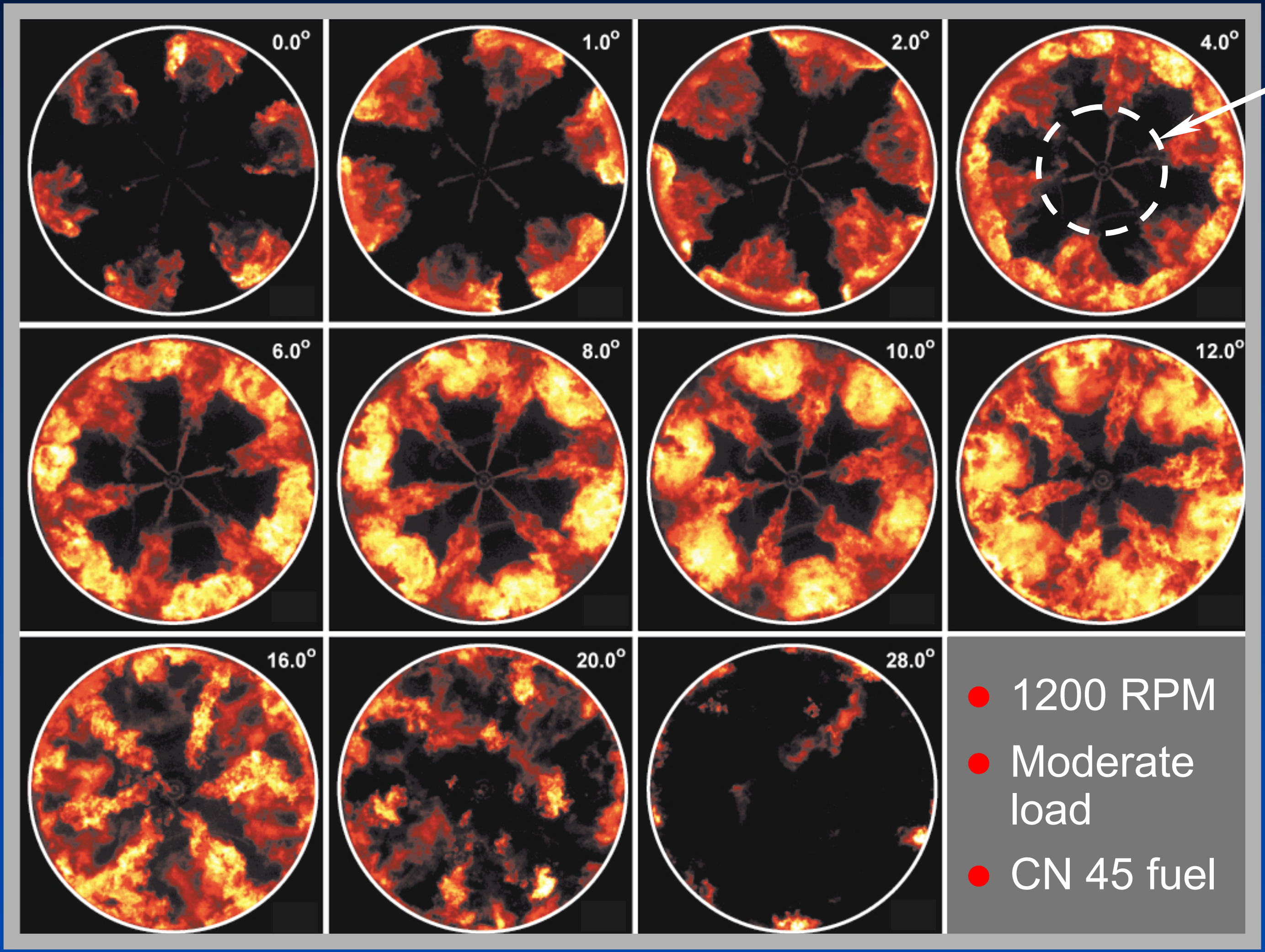
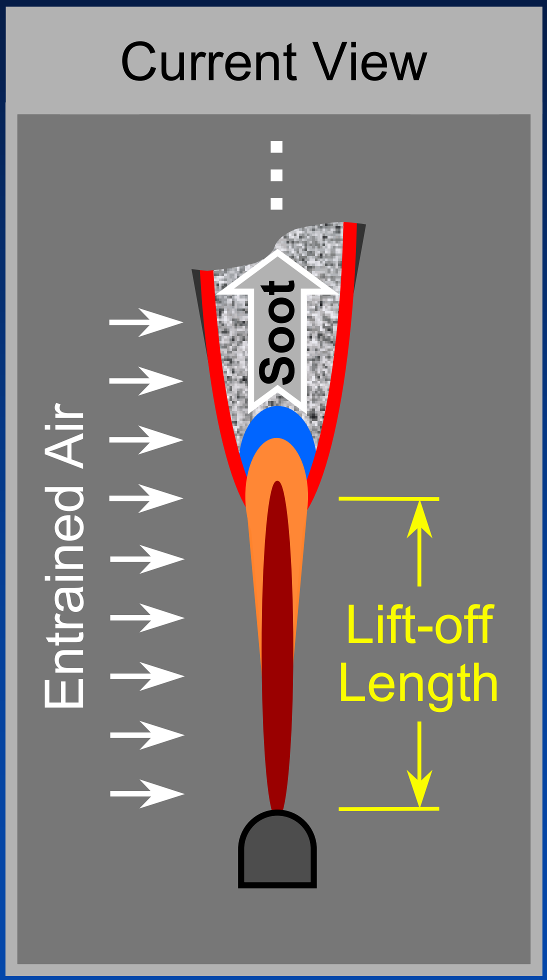
Direct luminosity images showing lift-off in a Cat 3171 with a HEUI injector.



- 1200 RPM
- Moderate load
- CN 45 fuel

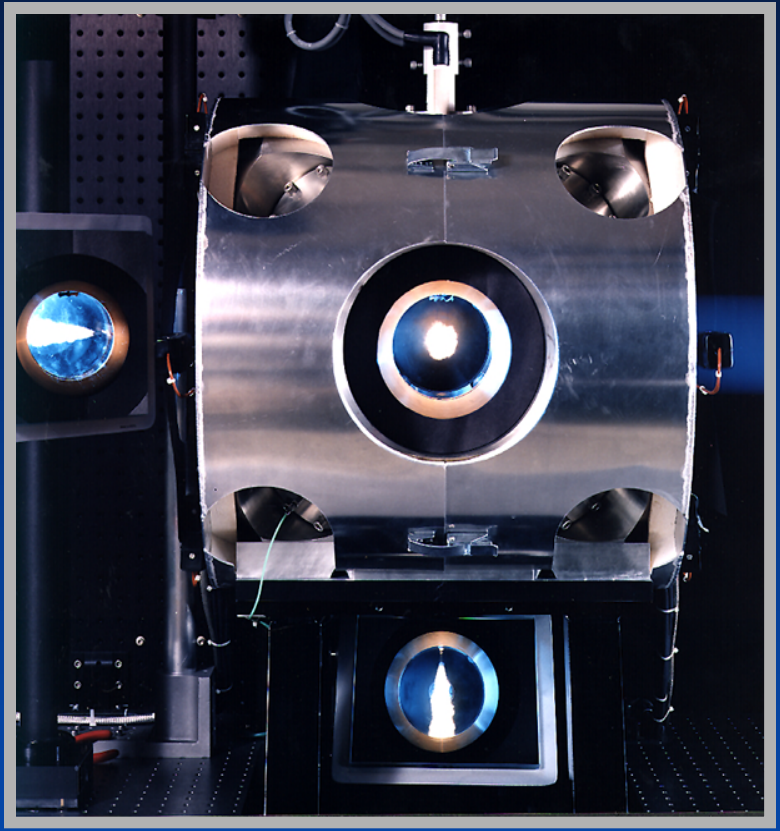
(Mueller and Musculus, 2001)

Objectives of the soot investigation.



- Measure soot distributions downstream of the lift-off length:
  - #2 diesel fuel, paraffinic fuels.
  - low-sooting (oxygenated) fuels.
- Parameters considered:
  - orifice diameter.
  - injection pressure.
  - ambient gas:
    - temperature.
    - density.
    - oxygen concentration (EGR).
- Impact of fuel-air premixing upstream of the lift-off length.

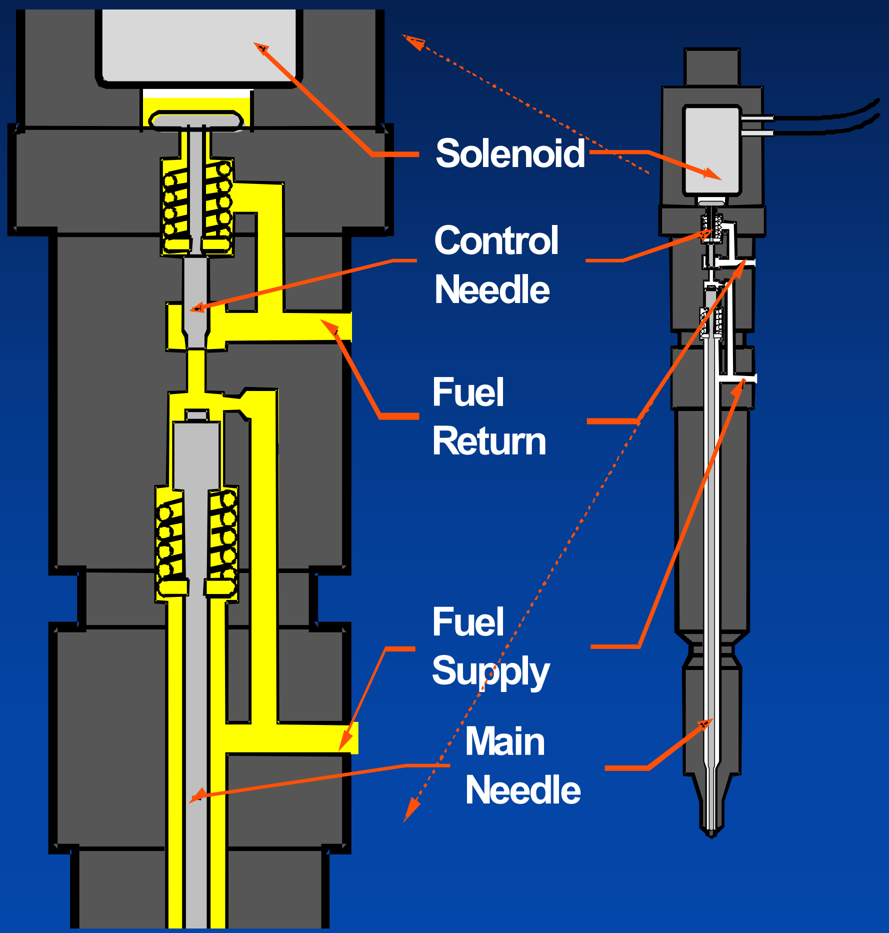
Research was conducted in an optically accessible combustion vessel.

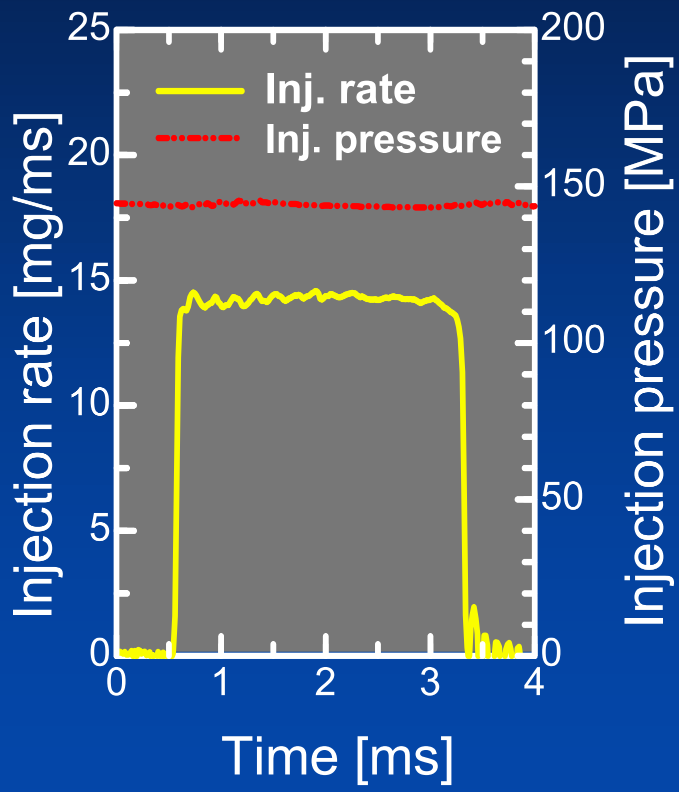


- Ambient gas conditions:
  - 15-21% O_2 (inert, EGR, air).
  - 800 - 1300 K.
  - 7 - 60 kg/m^3.
- Common-rail fuel injector:
  - 40 - 200 MPa.
- Single orifice tips:
  - 45 - 180 µm.

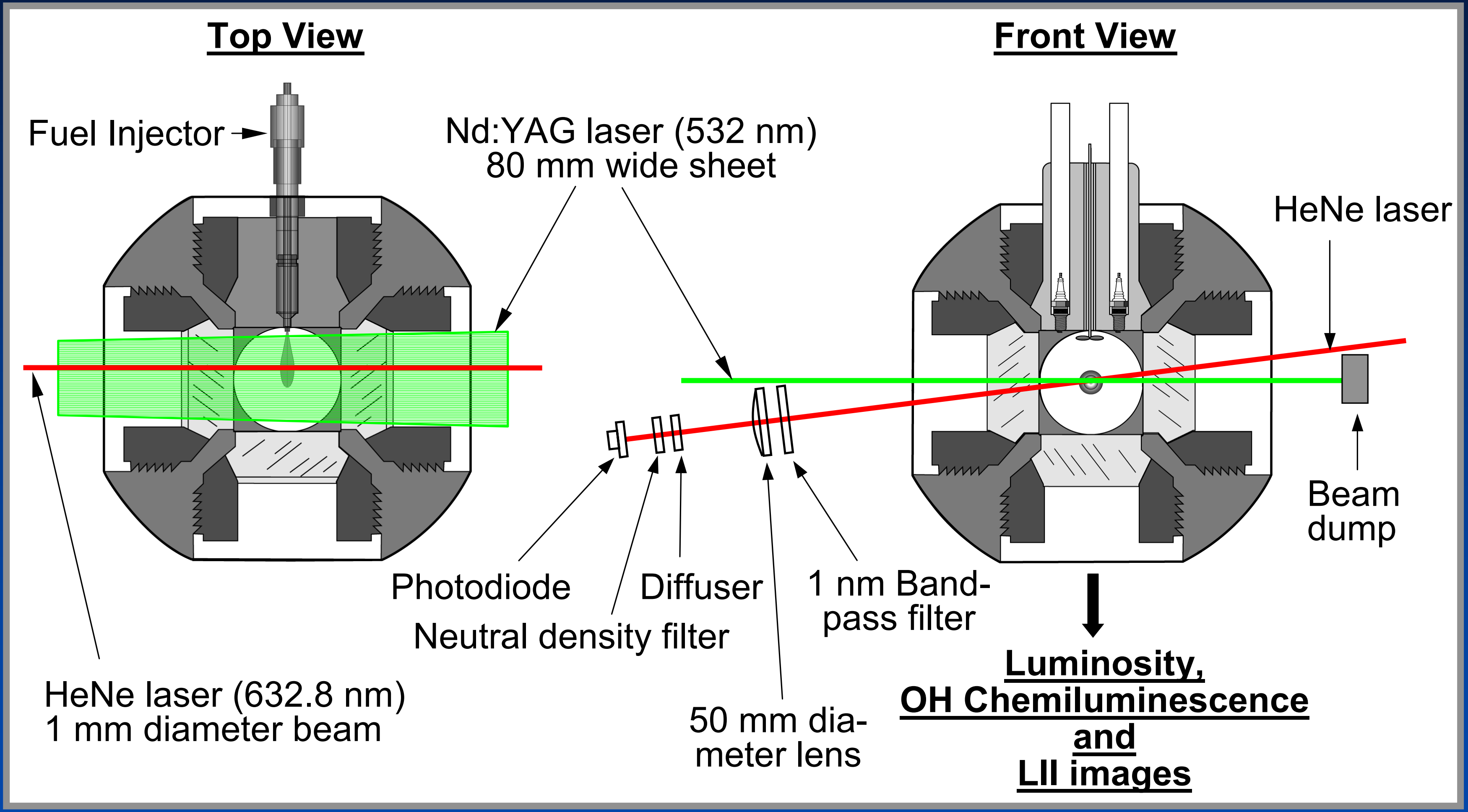
15% O_2 corresponds to 40% EGR at a high-load condition.

The fuel injector: electronically controlled, common rail, 200 MPa pressure rating.

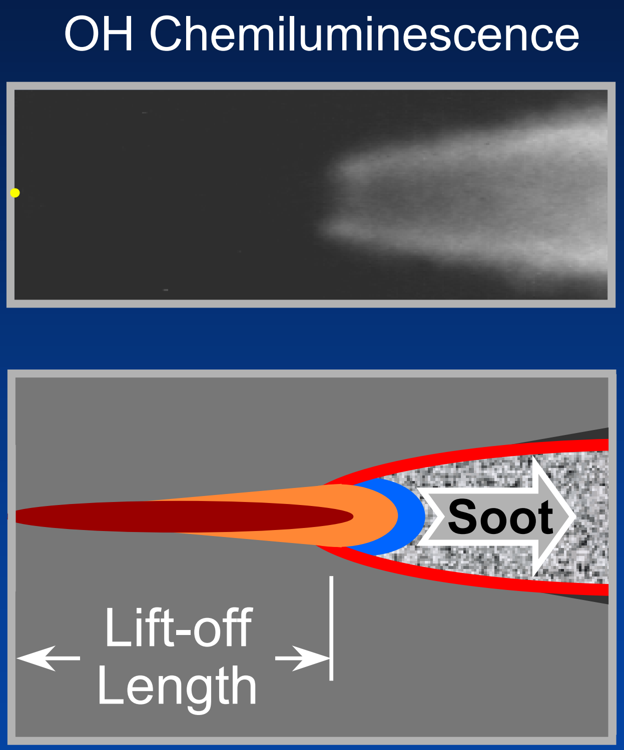




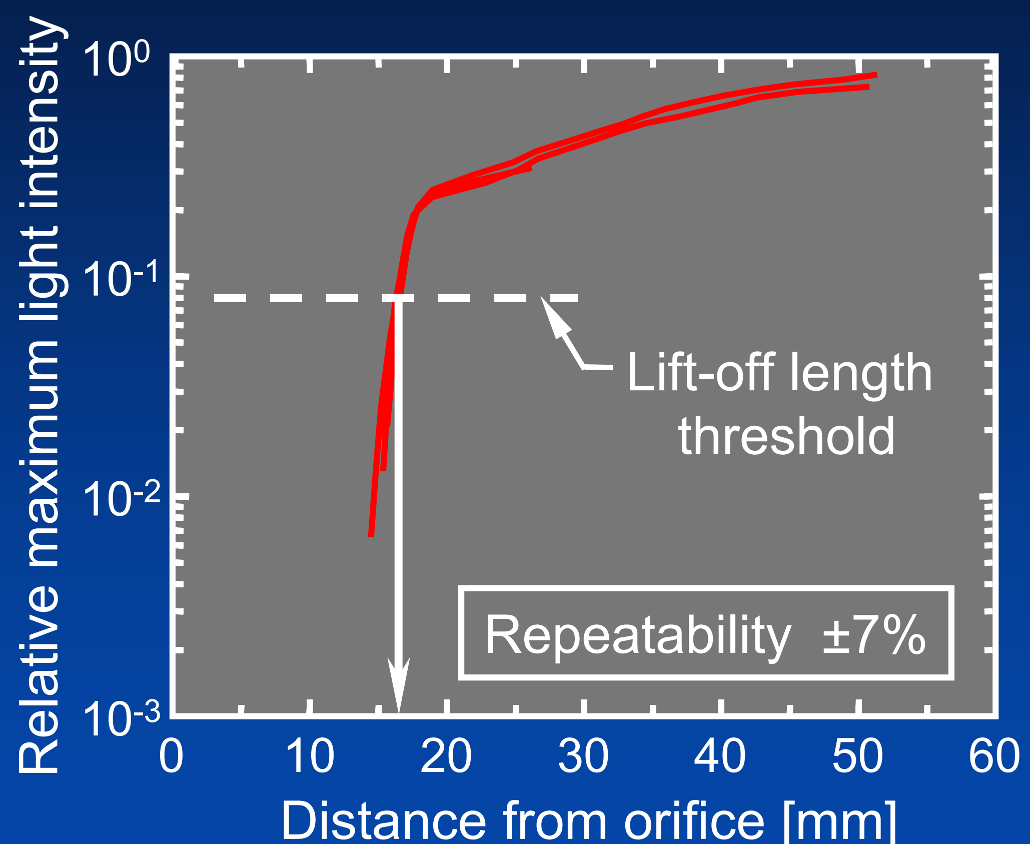
The soot measurements were made with two techniques: extinction and LII.



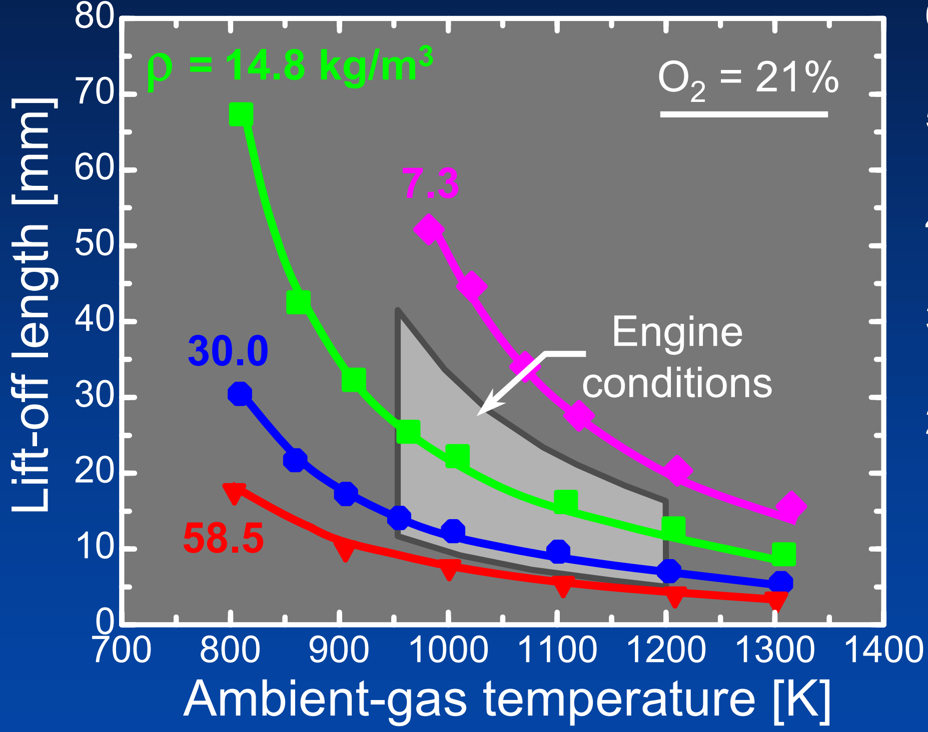
The lift-off length is determined from time-averaged images.

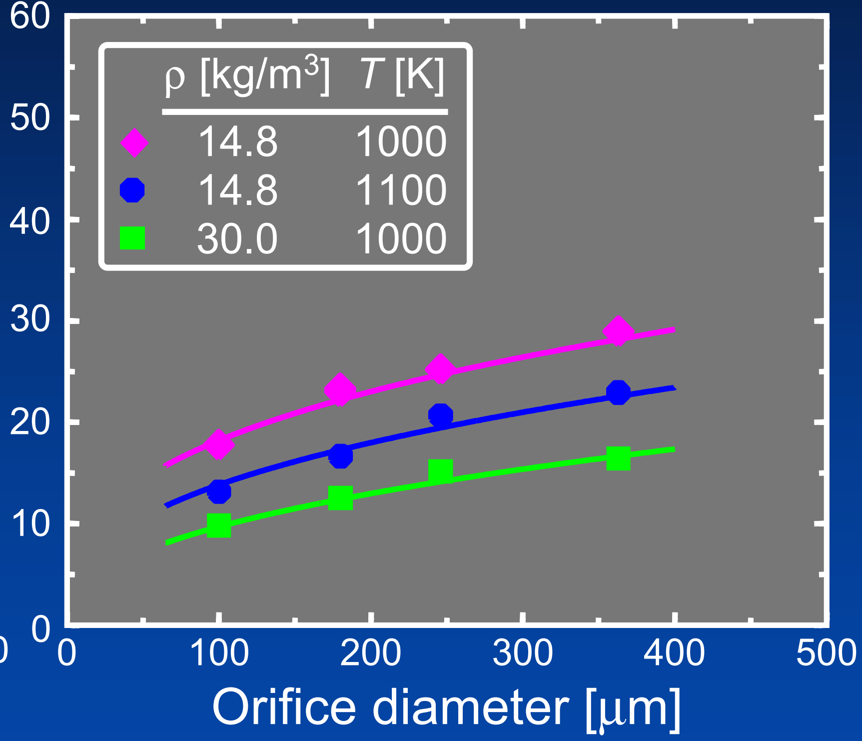


(see SAE 2001-01-0918)

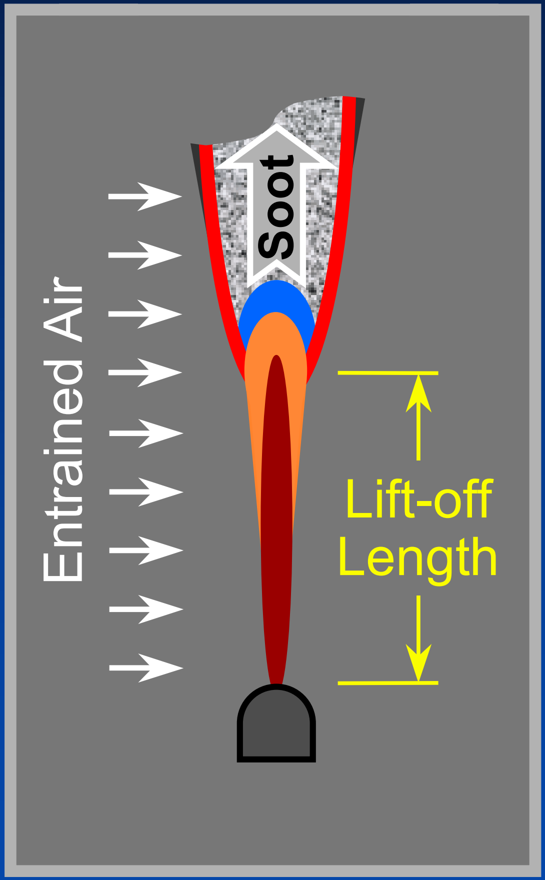


Lift-off on a diesel fuel jet can change significantly with changing conditions.





The lift-off length determines the amount of fuel-air mixing prior to combustion.

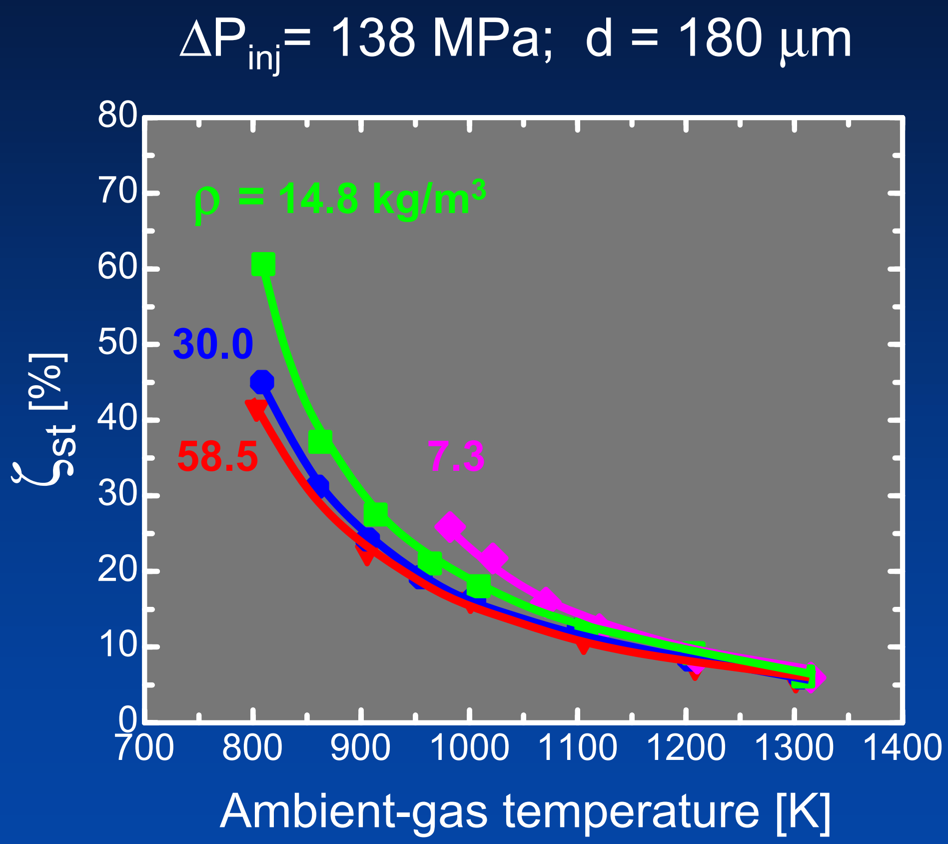


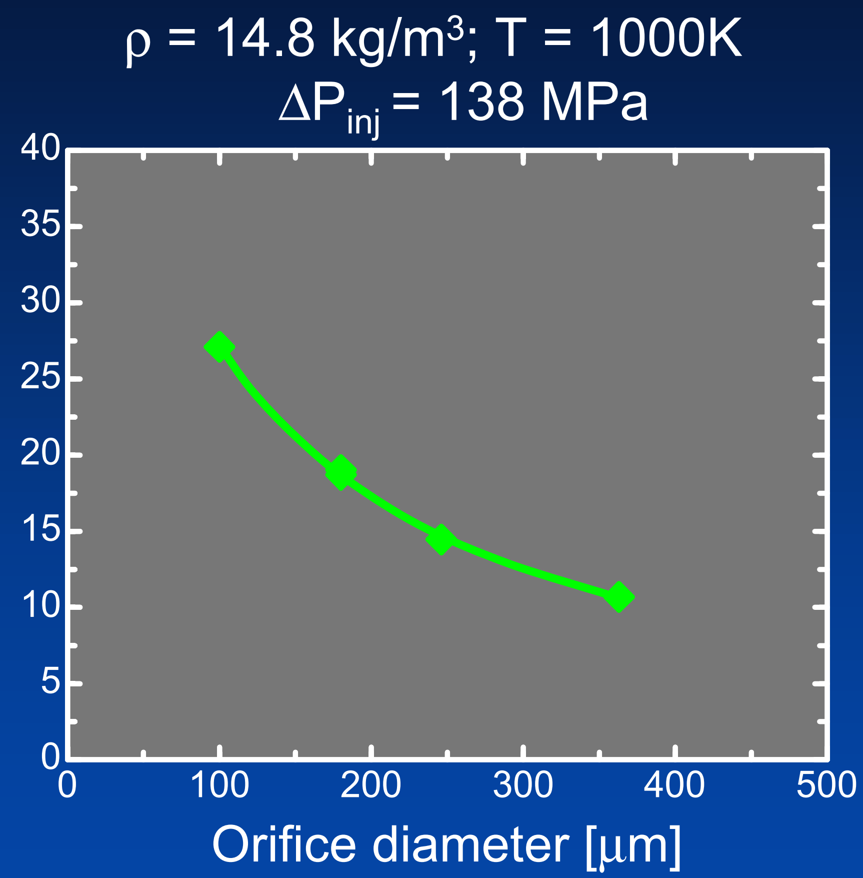
Percent of stoichiometric air entrained

$$\zeta_{st}(\%) = \frac{10}{3} \cdot \left(\sqrt{1 + 16 \cdot \left(\frac{x}{s^+} \right)^2} - 1 \right) = \frac{100}{\bar{\phi}}$$

$$s^+ = \frac{d}{\tan \alpha} \cdot \sqrt{\frac{\rho_f}{\rho_a}}$$

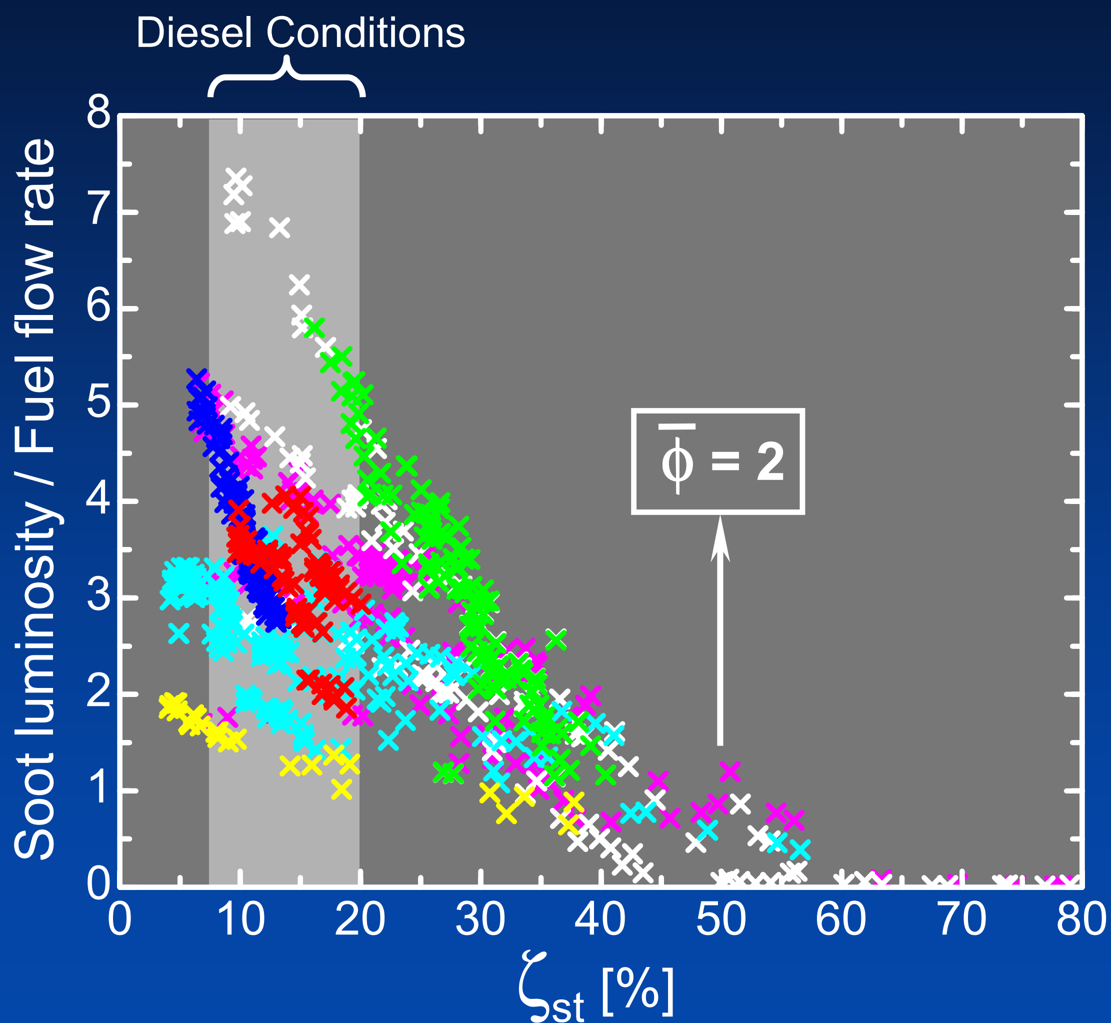
Fuel-air mixing is strongly affected by temperature, but not density.





- Soot reduction??

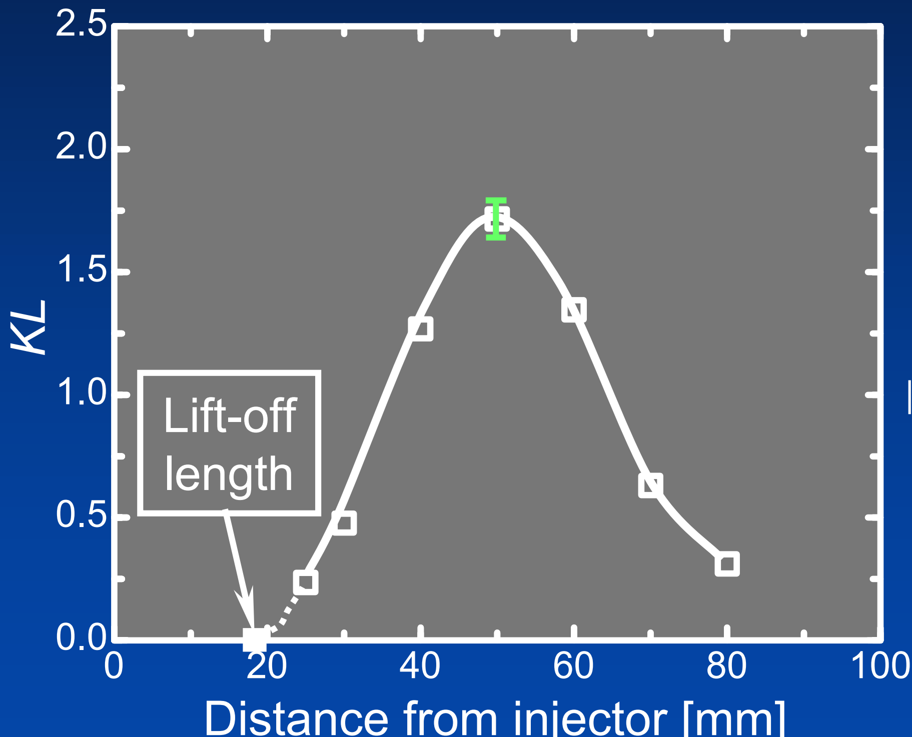
Fuel-air mixing upstream of the lift-off length plays a role in the evolution of soot.

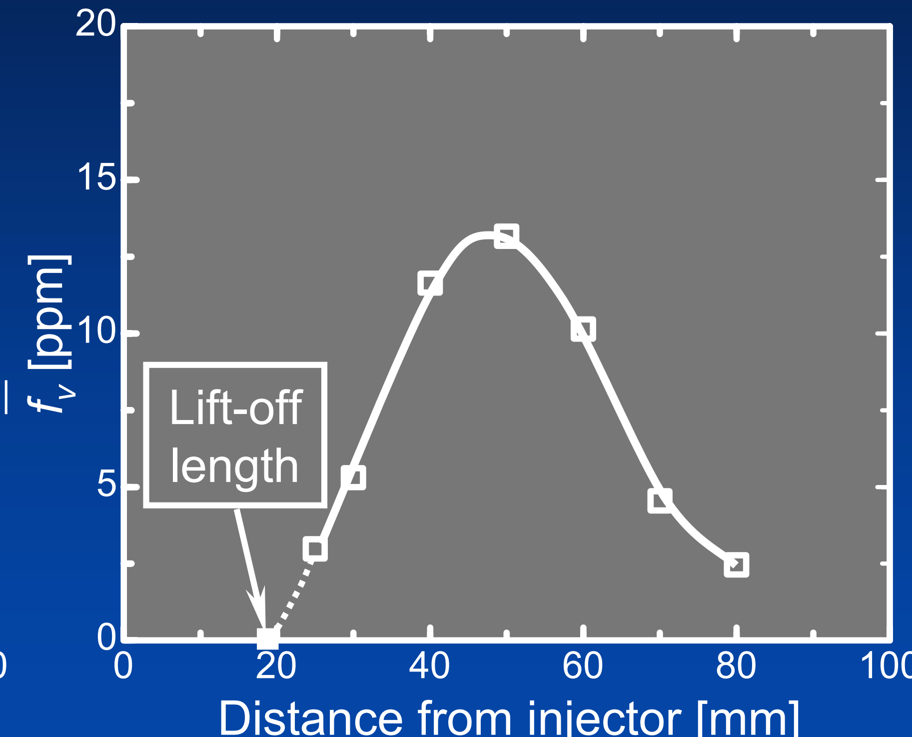


- Conditions:
  - 7.3 - 58.5 kg/m^3
  - 800 - 1000 K
  - 40 - 190 MPa
  - 100 - 363 µm
- Premixing affects soot formation.
  - more carbon to CO, less to soot precursors

Typical axial soot distribution.

ΔP_f = 138 MPa, d = 100 μm,
T_a = 1000 K, ρ_a = 14.8 kg/m^3

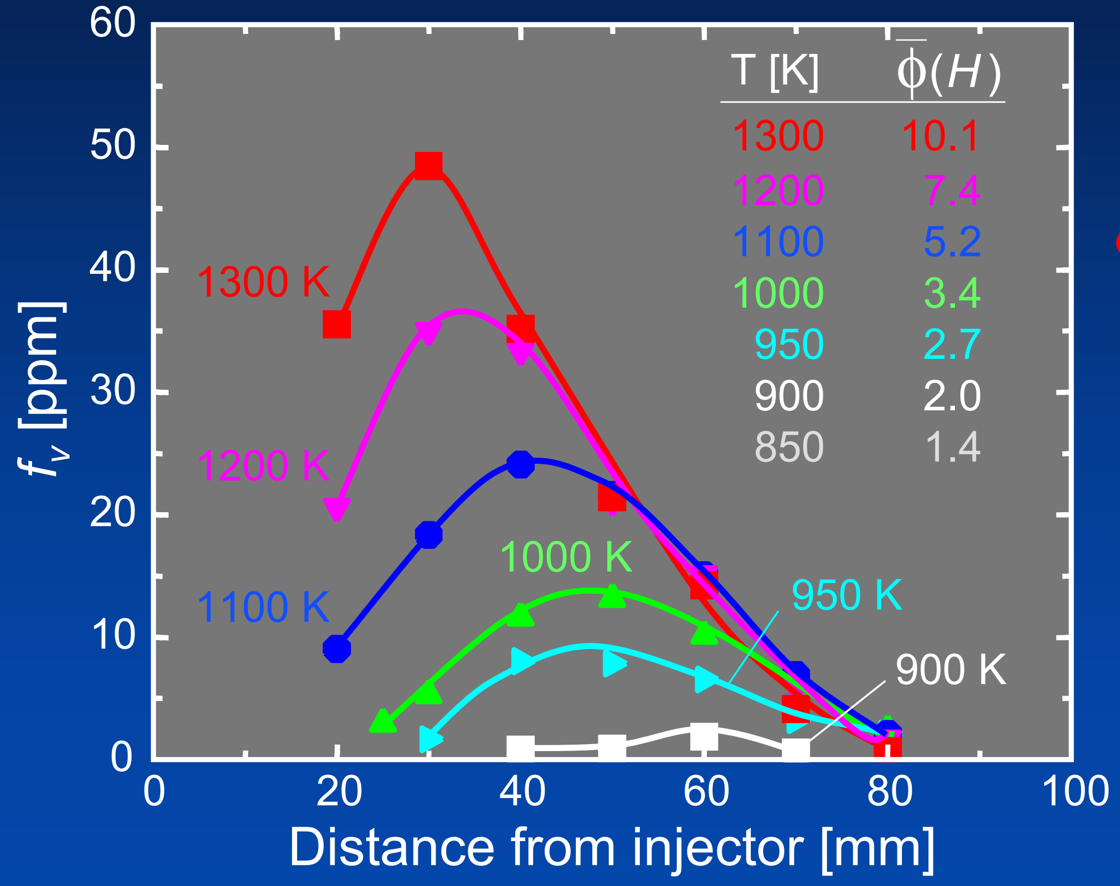




Similar to atmospheric pressure gas jets, but with more soot.

Peak soot levels increase with increasing ambient temperature.

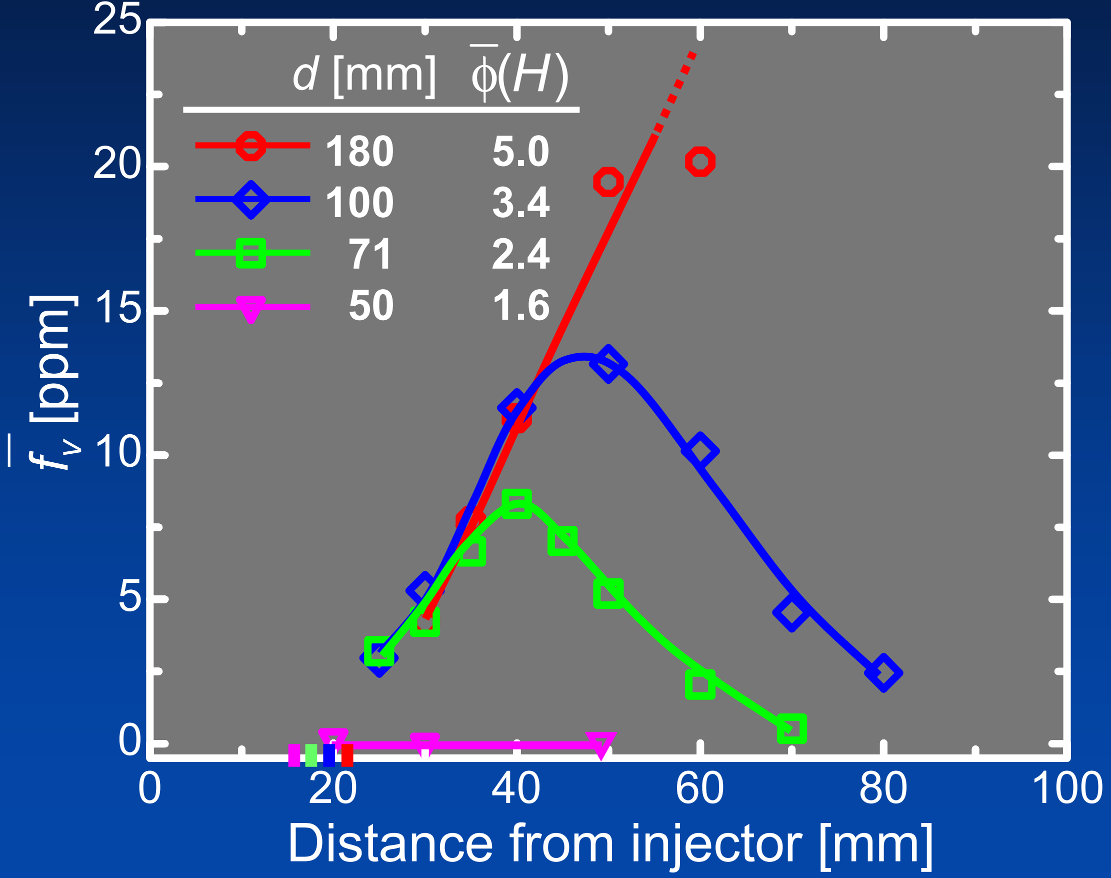
Conditions: d = 100 μm, ρ = 14.8 kg/m³, ΔP = 138 MPa



- The peak soot-volume fraction varies linearly with ambient temperature

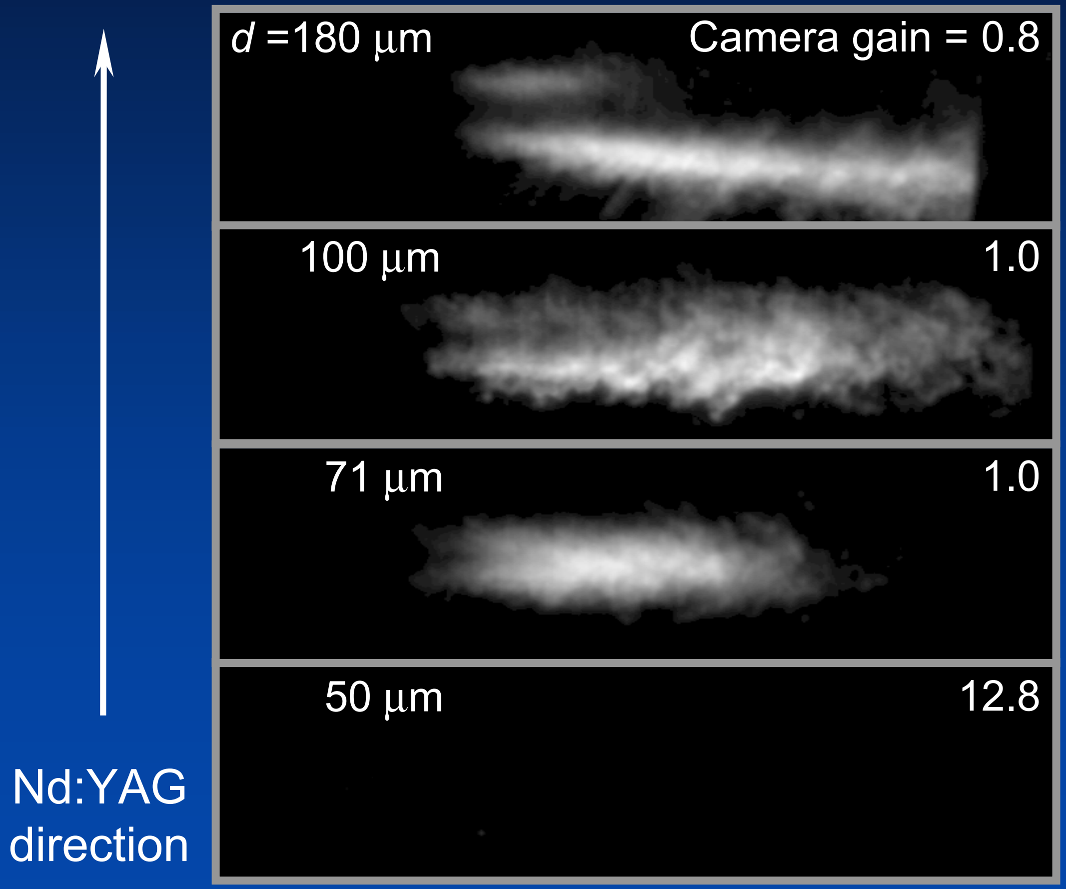
Soot within the fuel jet decreases with decreasing orifice diameter.

<u>Conditions</u>: ΔP_f = 138 MPa, ρ_a = 14.8 kg/m^3, T_a = 1000 K



LII images support the soot extinction measurements.

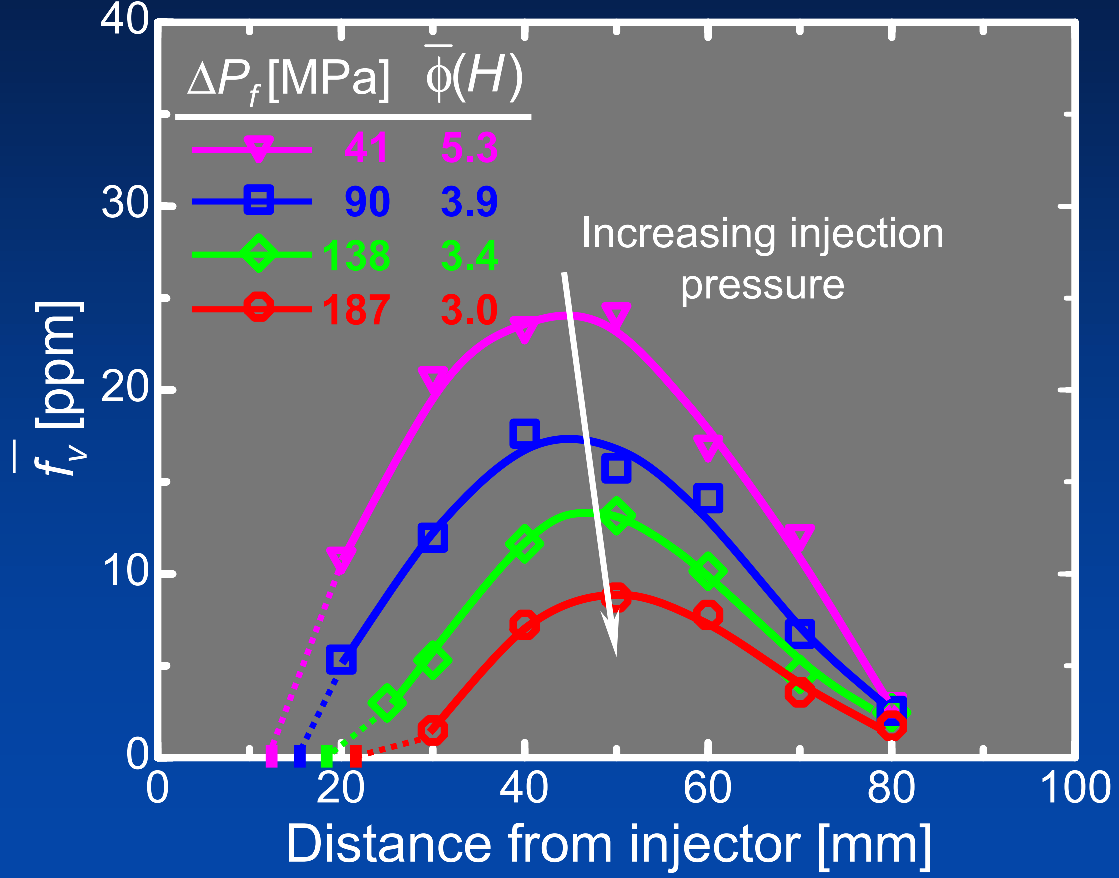
Conditions: ΔP_f = 138 MPa, ρ_a = 14.8 kg/m^3, T_a = 1000 K



- Averages of 12 or more LII images.
- Optically thick conditions for larger orifice diameters.

Soot within the fuel jet decreases with increasing injection pressure.

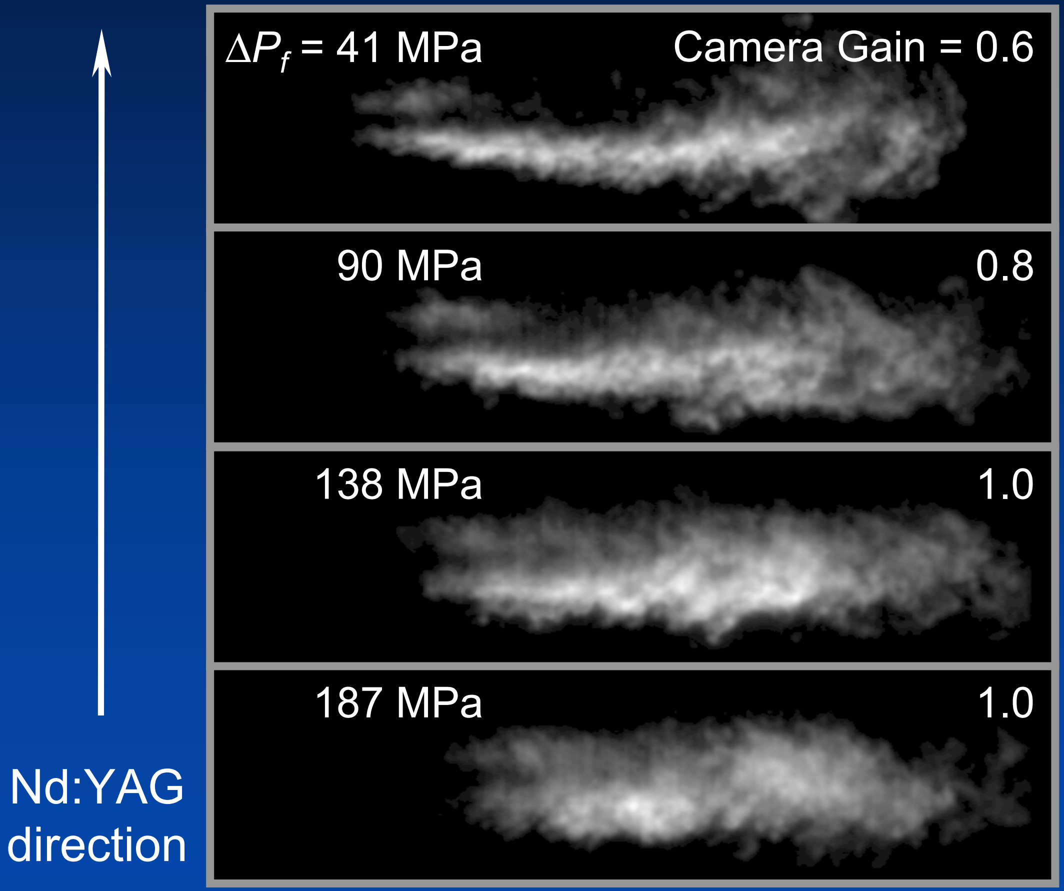
Conditions: d = 100 μm, ρ_a = 14.8 kg/m^3, T_a = 1000 K



- The peak soot-volume fraction varies linearly with injection velocity

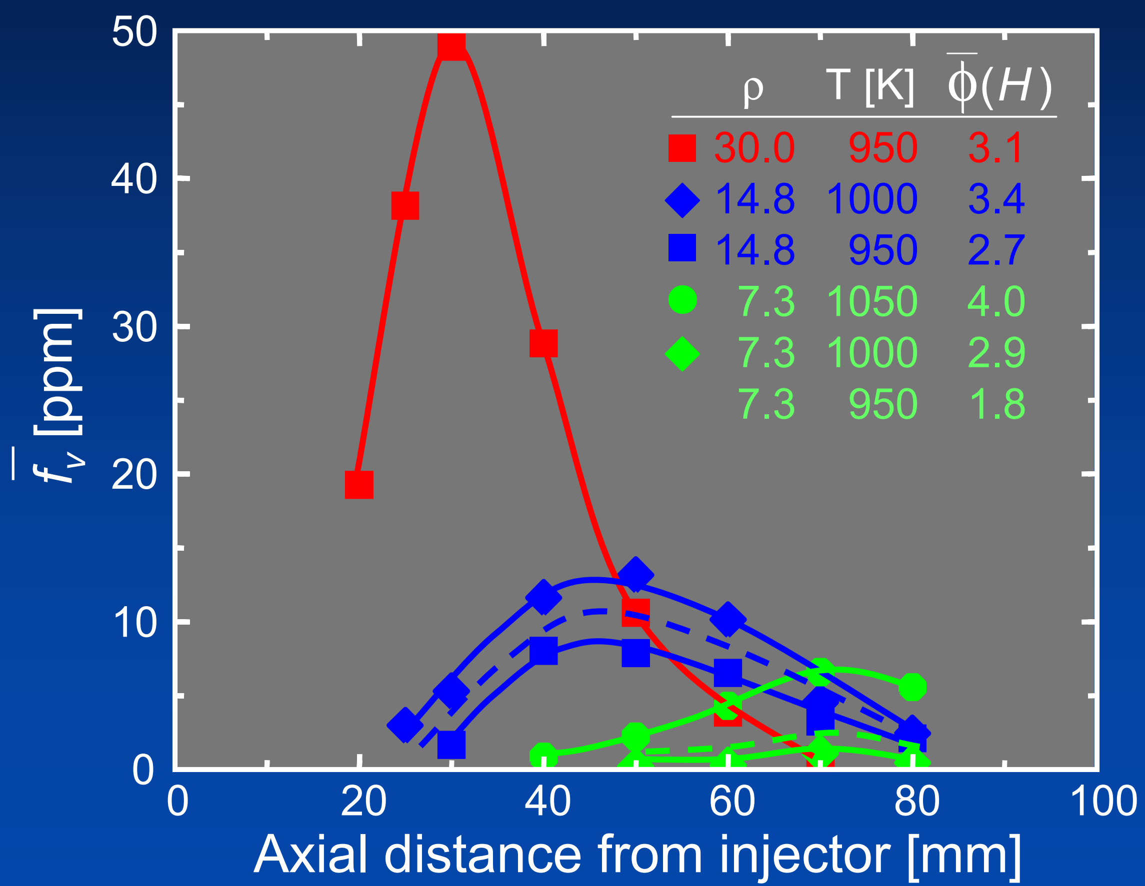
LII images support the soot extinction measurements.

- d =100 μm, ρ_a = 14.8 kg/m^3, T_a = 1000 K

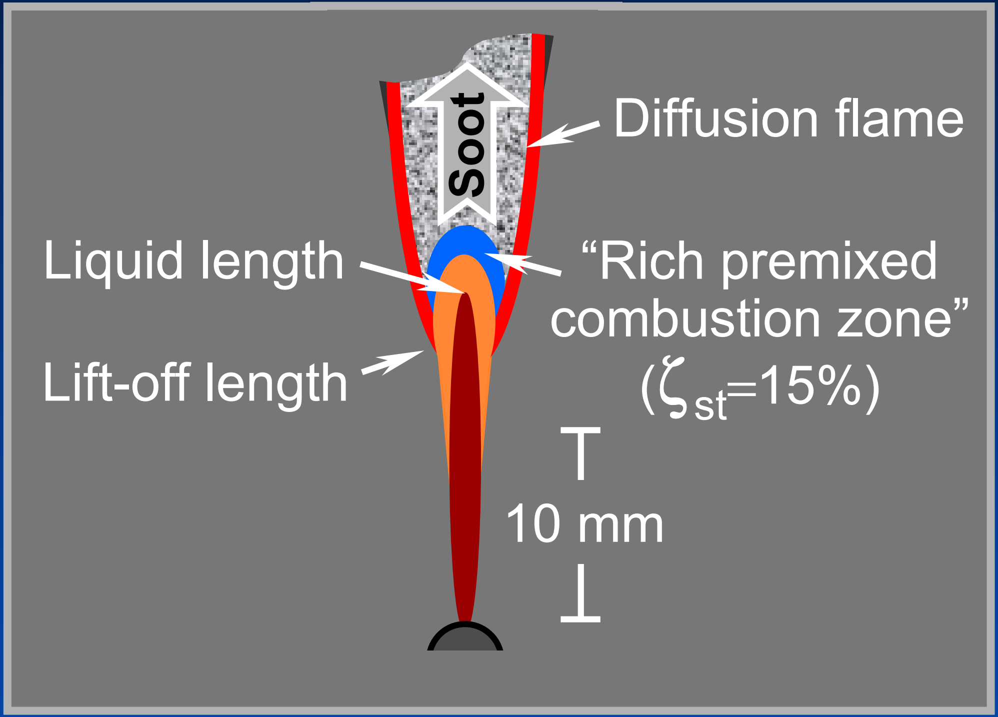


Soot increases with increasing ambient density.

Conditions: d = 100 μm, ΔP = 138 MPa

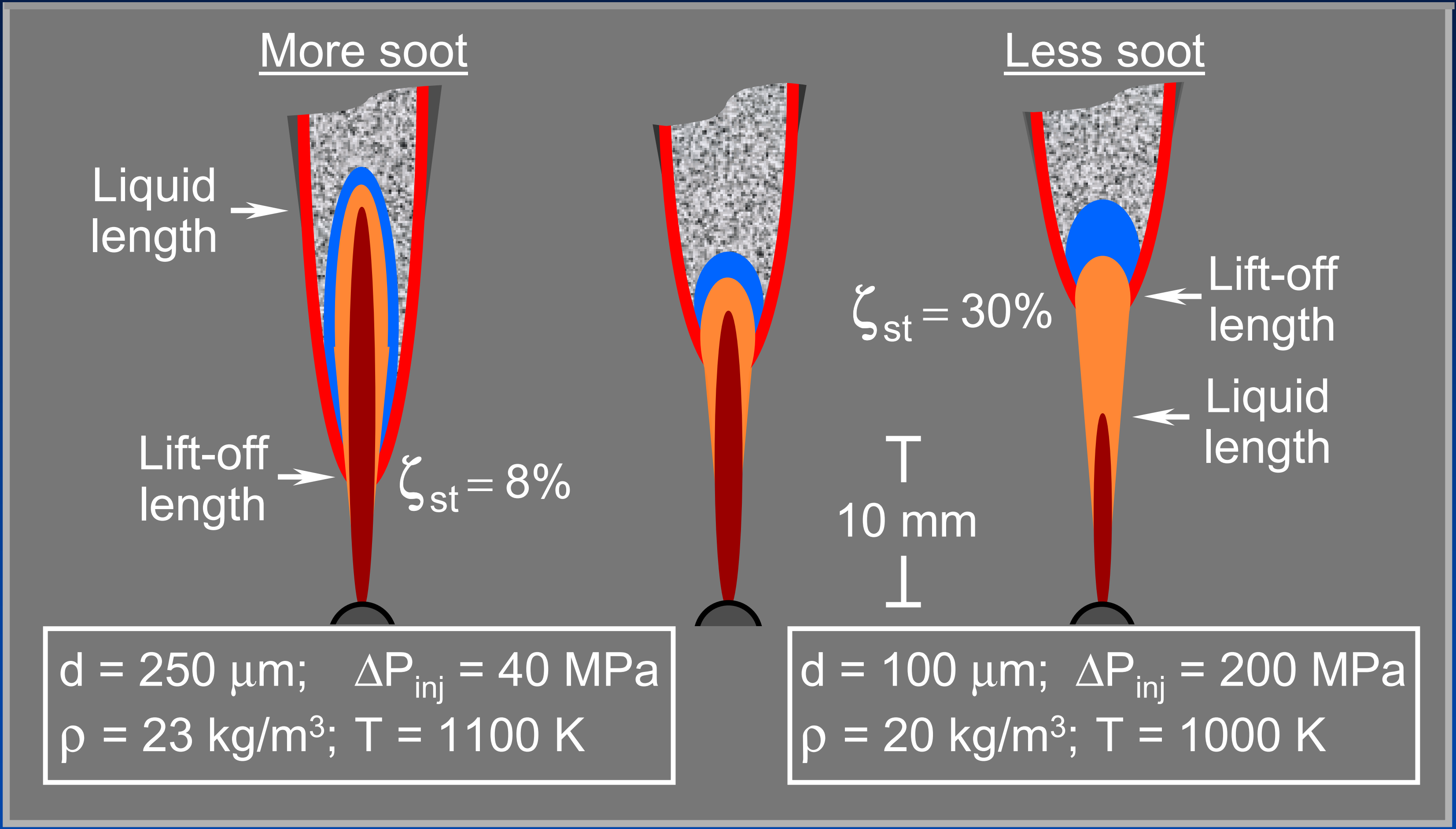


Implications for the overall structure of a fuel jet prior to wall impingement.



How does this picture change with conditions?

Implications for the overall structure of a fuel jet prior to wall impingement.



Summary and conclusions.

- Engine conditions (T and ρ) and injection parameters (d and ΔP_{inj}) affect lift-off:
  - changes in structure of a diesel fuel jet.
- Soot decreases with increasing ΔP_{inj} or with decreasing d, T, and ρ.
  - the peak soot varies linearly with ambient temperature.
  - the peak soot varies linearly with injection velocity.
  - no soot was formed with the 50 μm orifice at a moderate-load engine condition ($\bar{\phi}(H) = 2$).
- The amount of soot in a diesel fuel jet is strongly linked to the amount of fuel-air mixing upstream of the lift-off.