Determination of soot size and concentration in combusting diesel sprays by optical methods under conditions similar to low temperature combustion (LTC)

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Introduction

During the last decades, special attention has been devoted to the development of direct injected (DI) compression ignition engines [1]. This development has been partly achieved with two directives: a) investigating and improving the atomisation process, largely responsible for the mixing between fuel and oxidiser and b) conceiving novel combustion strategies or improving the existing ones. However, even if these novel combustion strategies have helped to fulfil the standards set by environmental legislations by lowering, in overall, the total emission of particle matter to the atmosphere, these have also raised the suspicion of achieving these goals by reducing the size of the emitted particles but increasing the number of them. It is then feared that if this scenario is correct, the increase in the number of smaller particles could worsen the health problems associated to airborne particles produced by combustion.

Low Temperature Combustion (LTC) is one of the strategies profiled as an alternative to meet the future legislation regarding both particle matter and nitrogen oxides. This is achieved by using high amounts of EGR or low compression rations which provide certain control over the combustion temperature and ignition delay. Unfortunately, these long ignition delays can cause the formation of large number of small carbonaceous particles inside the cylinder [2]. Under the normal operation of diesel engines this would not represent a problem since these particles would be oxidised before the exhaust valve opens; nevertheless, the temperature inside the combustion chamber, when using LTC, is not high enough to oxidise them before they are released to the environment [3]. This paper presents two-dimensional measurements of particle size and particle concentration in combusting diesel sprays at conditions similar to those prevailing in direct injection compression ignition engines operated under LTC.

Experimental arrangement

Soot measurements were done with simultaneous planar Laser Induced Incandescence (LII), Elastic Light Scattering (ELS) and Light Extinction (LE). Due to the relation between the size of the spray and the height of the laser sheet, the spray was divided into four different regions, vertically translating the combustion chamber to study each of them. The laser sheet had a height of 24 mm, a wavelength of 532 nm and a Gaussian temporal profile with a FWHM of 12 ns. The laser pulse was divided into two overlapping pulses delayed by 24 ns, the first one with an energy of 5 mJ for elastic scattering and a second one with an energy of 40 mJ for LII. The elastic scattering and the LII signals were acquired by two intensified CCD cameras. Before each camera there was an optical filter; the elastic scattering camera had an interference filter centred at 532 nm with a FWHM of 10 nm and the LII camera a long-pass filter whose transmittance starts at 570 nm. Extinction was measured with the aid of two beam samplers and two opaque plates; one beam sampler was set before the combustion chamber and one after, impinging the sampled laser beams on to the opaque plates. The opaque plates were imaged onto the one of the CCD cameras.

These studies were carried out in the Chalmers High Pressure, High Temperature (HP/HT) Spray Rig. The Chalmers HP/HT spray rig is a large-volume and optically accessed combustion chamber through which preheated and pressurised air flows uninterruptedly with a constant velocity. The conditions inside the combustion chamber, quiescent before injection and isobaric throughout, were controlled to achieve operational conditions representative to those in a diesel engine under two scenarios: a) Low Temperature Combustion (LTC), P_g=50 bar and T_g=520 °C, and b) normal operational conditions, P_g=70 bar and T_g=560 °C. Fuel was injected using a common rail injection system equipped with a single-hole nozzle which orifice has a diameter of Ø=0.15 mm. The fuel pressure inside the rail was maintained constant at P_{inj}=800 bar. Measurements were done at t=2.5 ms after the start of injection (ASOI) for both operational conditions.

Evaluation model

The method basically uses a non-continuum heat transfer model for the evaluation of the LII measurements, calculates the laser fluence across the flame and compensates for signal trapping, allowing measurements where laser extinction between the flame borders reaches values up to 90 %. The method was implemented by measuring particle size and concentration in the middle coronal axis of optically dense, combusting sprays at a certain time after the start of combustion. Further details of the method and measuring uncertainties can be consulted elsewhere [4].

Results and conclusions

Measurements of particle size, particle concentration and soot volume fraction across the coronal plane of the combusting spray were conducted for the studied conditions. Figure 1 shows averaged and two-dimensional measurements of soot volume fraction at the studied conditions. Figure 2 show particle size distributions at two heights below the nozzle (HBN), z_a=55 mm and z_c=75 mm, for LTC and normal operational conditions, respectively.

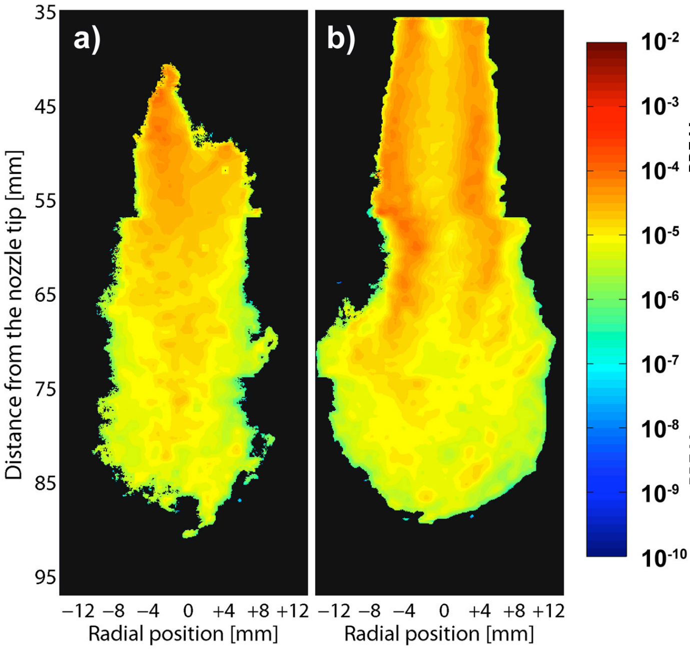

Figure 1. Soot volume fraction (fv) for a) LTC and b) normal operational conditions.

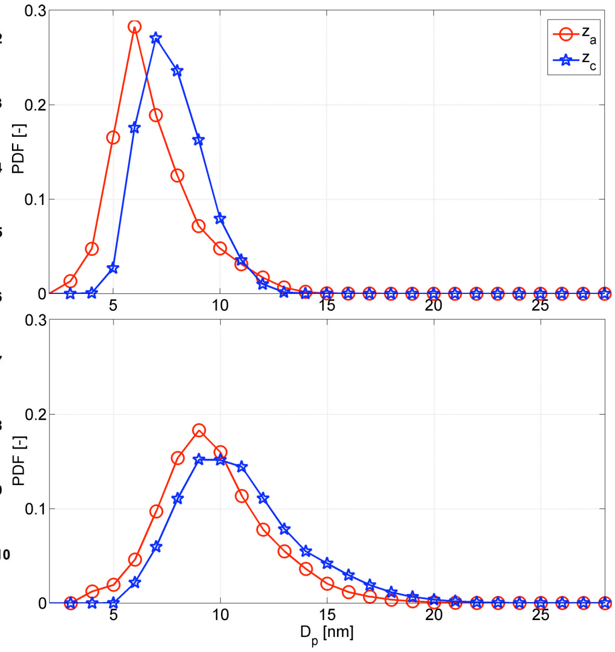

Figure 2. PDF for LTC (top) and normal conditions (below).

Results show that, although the differences in the maximum soot volume fractions between conditions differ little, LTC yields, in general, to relatively lower mean volume fractions of soot but presents higher numbers of smaller particles than under normal diesel combustion. This can be attributed to the longer ignition delay present in LTC (t_{id}=2 ms) compared to normal conditions (t_{id}=1.2 ms) which may promote the formation of larger number of smaller particles.

Acknowledgements

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Motivation

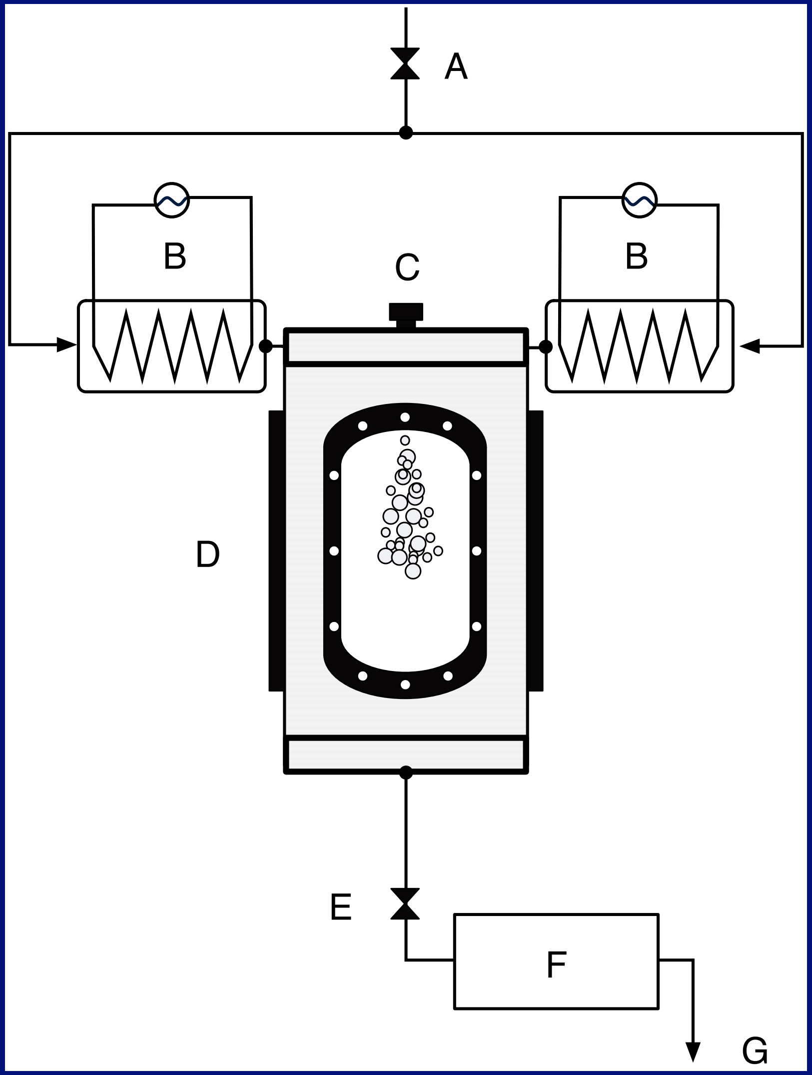
- Soot emission, from mobile combustion sources, is regulated by a stringent legislation which restrictiveness will be further increased
- “Modern” combustion strategies, capable of reducing PM emissions, must be studied in order to avoid the release of a myriad of very small particles

Description of the study

- Optical laser-based studies of combusting diesel sprays at two operational conditions measured 2.5 ms ASOI:
  - “Normal diesel engine” conditions
    - T_{gas} = 560 °C, P_{gas} = 70 bar & P_{inj} = 800 bar
    - Ignition delay t_{id} ~ 1.2 ms
  - Low Temperature Combustion (LTC)
    - T_{gas} = 520 °C, P_{gas} = 50 bar & P_{inj} = 800 bar
    - Ignition delay t_{id} ~ 2 ms

Chalmers HP/HT spray rig

- Combustion chamber where compressed and preheated air flows through
- Optically accessed
- Single-hole nozzle
- Open volume
  - Quiescent before combustion
  - Isobaric throughout



Utilised method

- Combines Laser Induced Incandescence (LII), Elastic Light Scattering (ELS) and Light Extinction (LE)

LII & LE - Soot volume fraction

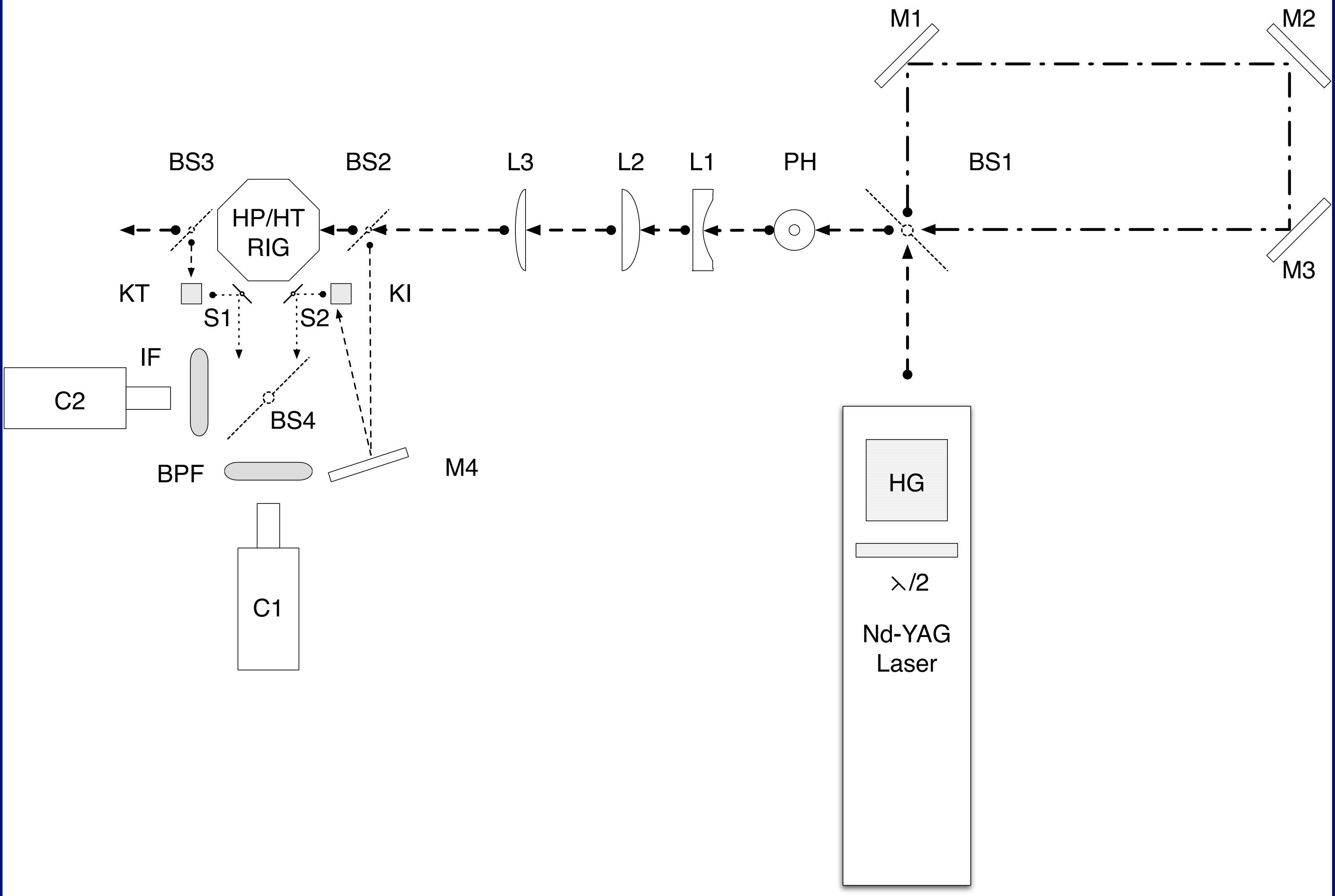
ELS / LII - Particle size

→ Particle concentration

Errors and uncertainties

- Based on the developed model assumptions:
  - f_v ~ 30%
    - Experimental
    - Model
  - D_p coupled to N_p
    - An error up to ~30% in D_p leads to a twofold increase or decrease in the amount of particles
    - A variation of 50% in the LII signal results in an error of ~30% in D_p

Experimental configuration



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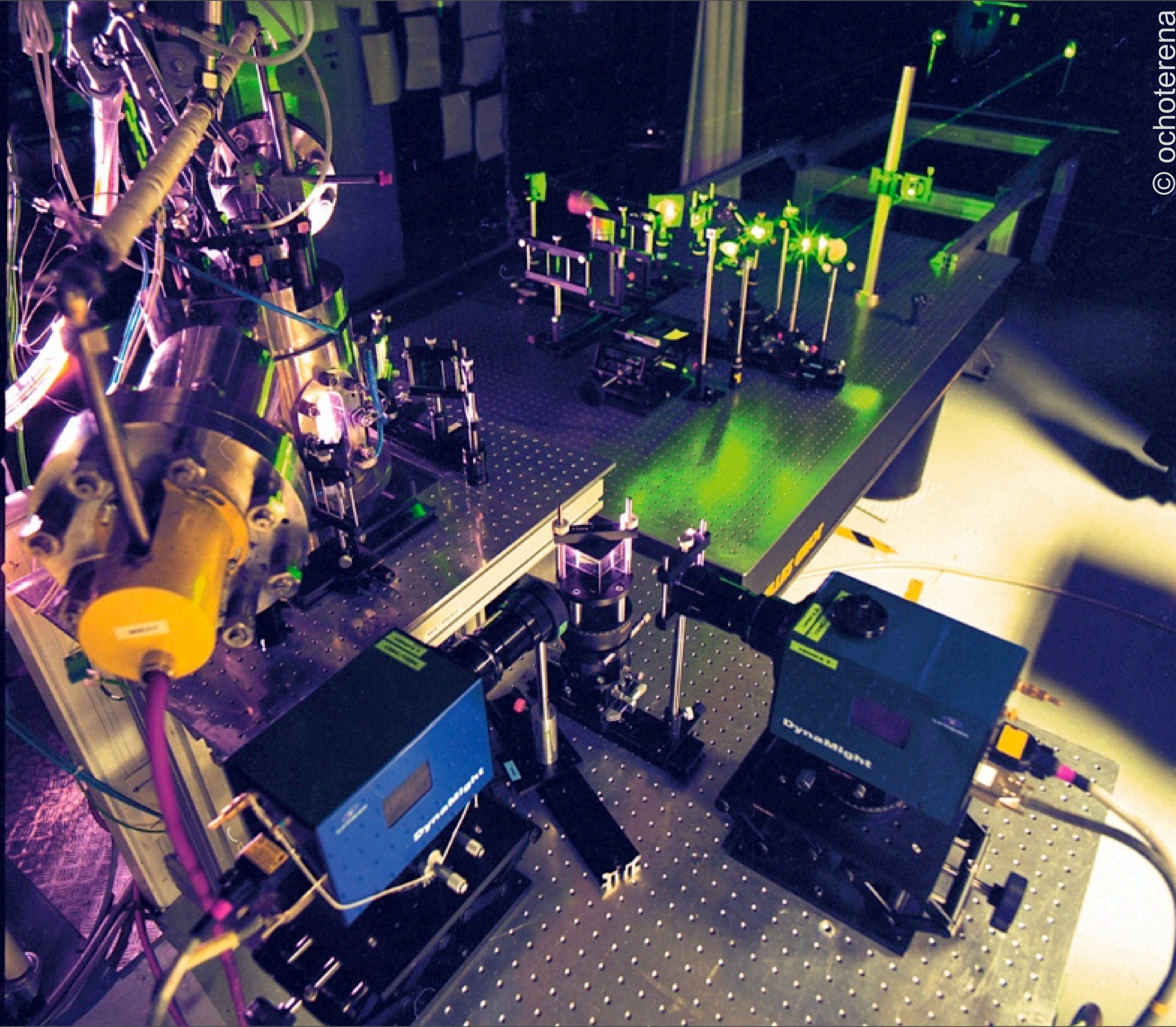
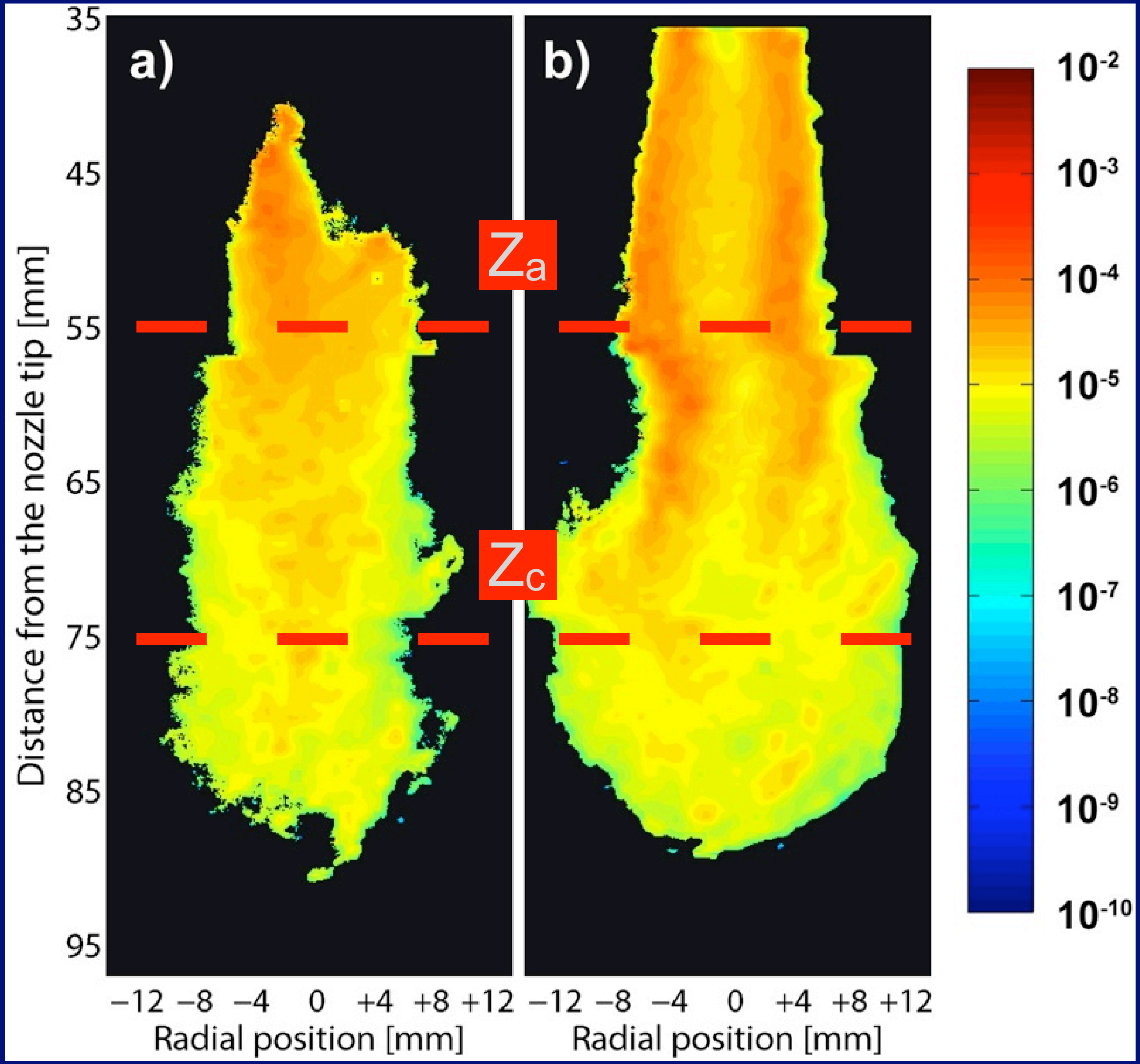
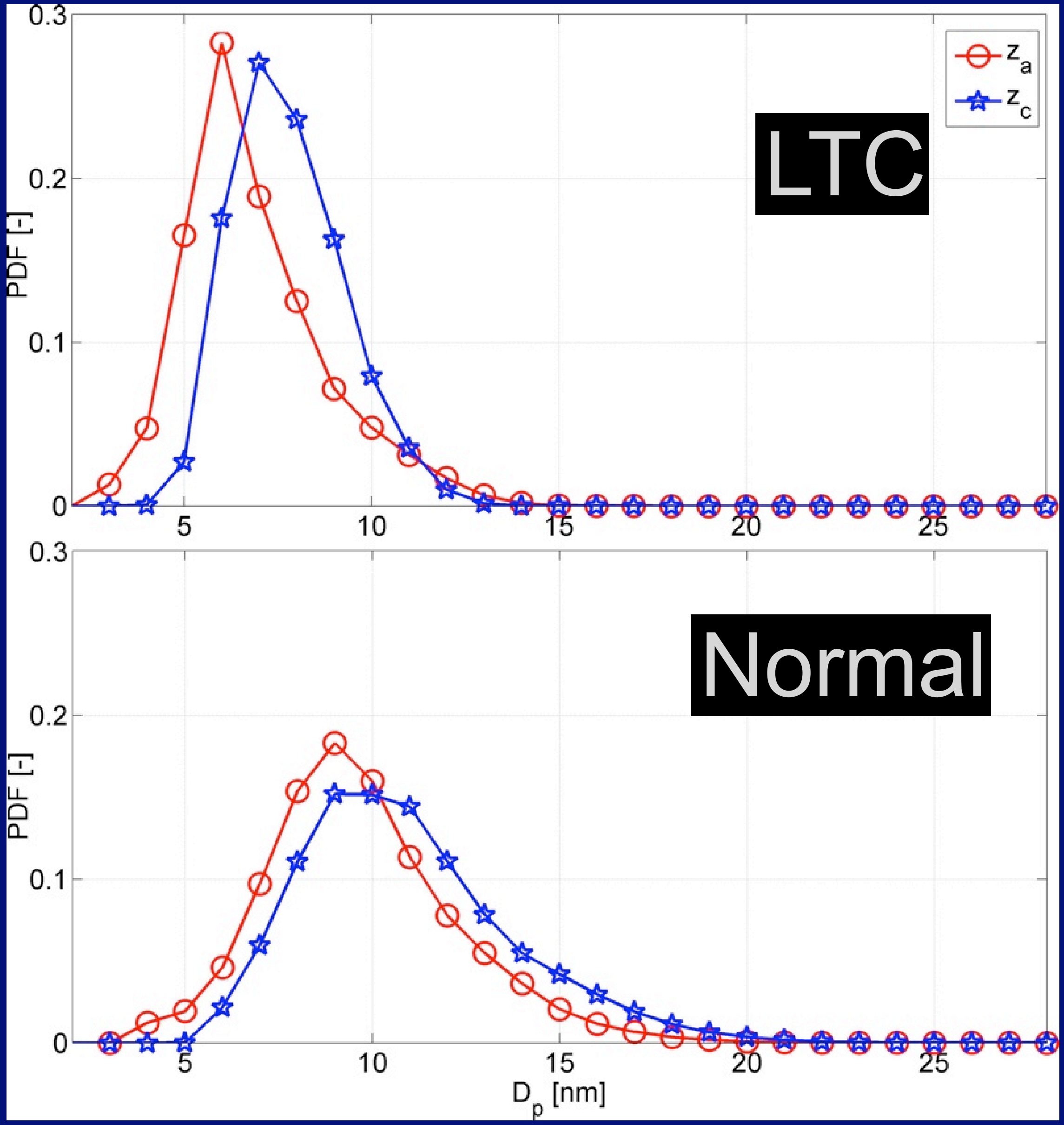


Soot volume fraction (f_v)



a) LTC
b) Normal

Probability density functions



Z_a=55 mm (HBN)
Z_c=75 mm (HBN)

Volume integrated values

	D_{mean} [nm]	N_{tot} [-]	V_{tot} [m^3]
LTC	7	10^{14}	10^{-13}
Normal	11	$2 \cdot 10^{14}$	10^{-12}

Conclusions

- LTC reduces the total amount of soot in the spray decreasing the mean particle size without affecting drastically the total amount of them
- The PDF´s mode value of LTC is located at much smaller values and has higher amplitude than in “normal diesel combustion”

Acknowledgements

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