Experimental study of soot formation : a focus on incipient soot particles

Dr. Christopher BETRANCOURT[1]

With contribution from Pascale Desgroux[2], Xavier Mercier[2] and Fengshan Liu[3]

[1] Laboratoire EM2C - CNRS & CentraleSupélec, Université Paris Saclay, 91190 Gif-sur-Yvette

[2] Univ. Lille, CNRS, UMR 8522 - PC2A - 59000 Lille, France

[3]Measurement Science and Standards, NRC Canada

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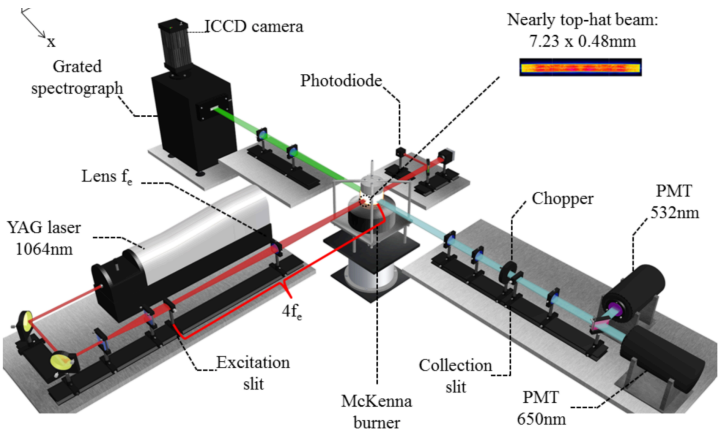
Emission of soot formed from incomplete combustion of fossil fuels, biofuels and biomass is a serious concern due to soot's harmful impact on human health, environment and its radiative forcing on climate. Gaining fundamental understanding of soot formation, particularly the nucleation step leading to the formation of the incipient soot particles, is critical to develop reliable predictive and realistic soot models and to help the design of more efficient and cleaner combustion devices.

Unfortunately, the mechanisms of gas phase species to particle transformation and the subsequent particle mass and size growth in hydrocarbon flames are still poorly understood. The experimental investigation of the flame zone in which nucleation occurs is difficult due to the concomitant processes of soot surface growth, condensation on soot and coagulation.

Recently, experimental studies [1-3] based on the Laser Induced Incandescence technique put in evidence at low and atmospheric pressure the existence of barely-sooting premixed flat flames or the so-called nucleation flames in which incandescent particles are formed with only marginal surface growth and coagulation along the flame. These nucleation flames are ideal tool for the study of incipient soot particles.

This work investigates the physicochemical properties of incipient soot particles in n-butane flat premixed standard sooting flame and slightly above the critical equivalence ratio (nucleation flame) at atmospheric pressure. To this end, a wide arsenal of experimental techniques have been combined:



-Optical techniques: laser-induced incandescence (LII), spatially designed for the detection of incipient soot particles (cf figure) and cavity ring-down extinction (CRDE).

-Ex-situ analysis by helium-ion microscopy (HIM) of particles sampled thermophoretically

- Online size distribution analysis of microprobe-sampled particles using a 1 nm-SMPS.

The size distribution of the incipient soot particles, found in the nucleation flame and in the early soot region of the standard sooting flame, derived from time-resolved LII signals are in good agreement with HIM and 1 nm-SMPS measurements and are in the range of 2–4 nm. The thermal and optical properties of incipient soot were found to be not radically different from those of mature soot commonly used in LII modeling. This explains the ability of incipient soot particles to produce continuous thermal emissions in the visible spectrum. This study demonstrates that LII is a promising in situ optical particle sizing technique that is capable of detecting incipient soot as small as about 2.5 nm and potentially 2 nm.

[1] T. Mouton et al., Applied Physics B, vol. 112, no. 3, pp. 369–379, 2013.
[2] H. Bladh et al., Proceedings of the Combustion Institute, vol. 35, no. 2, pp. 1843–1850, 2015.
[3] C. Betrancourt et al., Aerosol Science and Technology, vol. 51, no. 8, pp. 1–20, 2017.