Soot Primary Particle Sizing in Turbulent Flames via Combined LII & Elastic Light Scattering (ELS)

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Laser Induced Incandescence (LII) is often promoted as a real-time, in situ, spatially resolved optical method capable of measuring soot volume fraction f_v and soot primary particle diameter d_p through analysis of time-resolved incandescence data and the application of a soot cooling model. However, a key parameter of any soot cooling model is the local gas temperature since it drives the cooling process. While it is possible to spatially map a flame gas temperature field for steady flames, measurement in unsteady flames would require simultaneous measurement of the unheated gas temperature and the subsequent LII cooling curve to reliably determine soot primary particle diameter, thus limiting the applicability of LII soot sizing in unsteady flames.

The current work aims to avoid the need for gas temperature measurement and time-resolved LII by instead obtaining d_p as well as the soot radius of gyration R_g via combined LII and ELS. It has been shown that the absolute magnitude of backward scattering from soot aggregates is mostly independent of aggregate size, instead depending on primary particle diameter and soot volume fraction[1] while the ratio of a forward and backward scattering measurement can be used to measure R_g[2].

A 532 nm pulsed Nd:YAG laser operating at the cusp of the plateau regime is used to produce both LII emission and elastic light scattering. A single optical collection tube collects both LII emission and scattering at an angle of 150°. The collected signal is subsequently separated into three wavelength bands (two for auto-compensating LII and one for ELS), which are detected using photomultiplier tubes (PMTs). The PMT output is amplified and processed by a gated integrator to produce an average measurement during the gate width. ELS at an angle of 30° is collected by a second optical collection tube coupled to a fourth PMT.

Ensemble-averaged measurements made on the centerline of a buoyancy-driven non-premixed turbulent flame burning a mixture of mostly methane indicate d_p on the order of 20-30 nm and R_g from 60-100 nm for mean soot concentrations up to 0.15 ppm. Flame radiation has a negligible contribution to both the LII and ELS signals, as does secondary light scattering within the combustion enclosure. The bias uncertainty in the measurements is driven by the uncertainty on the soot refractive index absorption function $E(m_\lambda)$ and the calibration of the neutral density filters used to attenuate the PMTs used for scattering measurements, while the precision uncertainty is limited by photon shot noise.

[1] Teng, Y., & Koylu, U. O. (2006). Optical sizing of aggregated combustion particles: computational development of a two-angle laser scattering technique. *Applied optics*, 45(18), 4396-403.

[2] De Iuliis, S., Cignoli, F., Benecchi, S., & Zizak, G. (1998). Determination of soot parameters by a two-angle scattering-extinction technique in an ethylene diffusion flame. *Applied optics*, 37(33), 7865-74.