Effects of soot absorption and scattering on LII intensities in a laminar coflow ethylene/air diffusion flame

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A 3D radiation model in absorbing, emitting, and scattering media is presented to quantify the effects of absorption and scattering by soot particle present between the measurement volume and the detector.

Introduction

Detected LII signals in reality rarely reflect the *true* radiation intensities emitted by laser heated hot particles in the laser probe volume due to the presence of other particles between the probe volume and the detector, Fig.1. The particles in the path between the probe volume and the detector play two roles. On one hand, they attenuate the emission intensity through absorption and out-scattering. On the other hand, they enhance the radiation intensity in the direction towards the detector through emission and in-scattering. The degree of LII signal modification depends on several factors such as the concentration and radiative properties of the other particles at the detection wavelength.

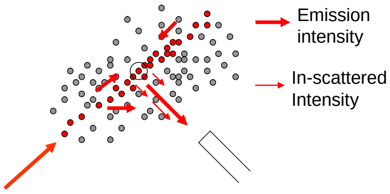

Fig. 1: A schematic illustrating the dual role of particles along the path between the laser probe volume and the detector.

It is important to gain quantitative understanding on the effects of particle absorption and scattering on the detected LII intensities. Such knowledge can be directly useful for improving the accuracy of particle temperature determined by two-color LII. Consequently, it helps improve the accuracy of LII based techniques for measurements of soot volume fraction, determination of soot absorption function E(m), and thermal accommodation coefficient.

Model and Method

We only concern the radiation intensity field at a moment near the end of the laser pulse when all the particles along the laser beam are heated to the same temperature. The radiation intensity is governed by the spectral radiative transfer equation

$$\xi\frac{\partial I_\lambda}{\partial x}+\eta\frac{\partial I_\lambda}{\partial x}+\mu\frac{\partial I_\lambda}{\partial x}=-(\kappa_{a\lambda}+\kappa_{s\lambda})I_\lambda+\kappa_{a\lambda}I_{b\lambda} +\frac{\kappa_{s\lambda}}{4\pi}\int_{\Omega'=4\pi}\Phi(\Omega'\to\Omega)I_\lambda(\Omega')d\Omega' \quad (1)$$

The radiative properties of polydisperse fractal soot aggregates are evaluated using the Rayleigh-Derby-Gans theory for polydisperse fractal aggregates (RDG-PFA). The scattering phase function is approximated by using the Henyey-Greenstein expression. The 3D spectral RTE is solved in cartesian coordinates using the discrete-ordinates method (DOM). To obtain the radiation intensity along an arbitrary direction, the DOS+ISW technique is employed.

Calculations were conducted in a laminar coflow ethylene/air diffusion flame with the distributions of soot volume fraction and temperature from experimental measured. To simulate the effect of the laser pulse, particles within 1 mm (simulating a laser beam about 2 mm) from the cord passing through z = 42 mm are assigned a temperature of 3600 K. Radiation intensities perpendicular to the laser beam were calculated. Table 1 summarizes the effects of absorption and scattering on the LII intensities at 400 nm and 780 nm detected horizontally at a height of z = 42 mm and passing through the flame centreline.

Table 1: Samples LII intensities at a selected detector location (in W/m^2 m ster)

	400 nm	780 nm
With scattering[a]	5.3136E10	9.8237E10
No scattering[b]	5.4495E10	9.8449E10
No in-scattering[c]	4.9635E10	9.7541E10
Emission only[d]	6.0265E10	1.0110E11

[a]Full simulation. [b]Scattering coefficient is set to 0.
[c]The in-scattering term in Eq.(1) is removed.
[d]Scattering coeff. is set to 0 and absorption coefficient outside the laser beam is also set to 0.

Scattering has stronger influence on the intensity at 400 nm. Further, attenuation is higher at 400 nm. Absorption and scattering clearly affect the ratio of the two LII intensities and thus the two-color LII particle temperature if no proper correction is made to the detected intensities.

Conclusions

A 3D radiation model was developed to quantify the effects of soot absorption and scattering on the detected LII intensities. Results of sample calculations in a laminar diffusion flame confirm that such effects are nontrivial and further studies are required.

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International Discussion Meeting and Workshop 2006: Laser-induced Incandescence, Quantitative interpretation, modelling, application