Account for extinction and multiple scattering in planar droplet sizing of dense sprays

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Planar Droplet Sizing (PDS) has been performed in the near development field of a spray produced by coaxial air-blast atomization. Interest of this imaging technique lies in its capability for rapid droplet sizing in planes taken through the spray whereas point measurement by Phase Doppler Anemometry (PDA) is not suitable for application in dense sprays. When a plane (x,y) of the spray is illuminated by a laser sheet, the local power of elastic light scattering is proportional to the local interfacial area within the light sheet according to

$$P_s(x,y) \equiv \alpha\, I\, \Sigma N_i d_i^2$$

where summation is made over the distribution of droplet area, I is the local laser irradiance and α is non dimensional parameter (polar albedo) of the Lorenz-Mie theory.

If the liquid phase is able (or doped with a dye) to absorb a weak fraction of the laser radiation and re-emit fluorescence, the local power of fluorescence is proportional to the local volume of liquid within the light sheet according to

$$P_f(x,y) \equiv \beta I\, \Sigma N_i d_i^3$$

where summation is made over the distribution of droplet volume and β is a spectroscopic constant in m^{-1} proportional to the absorption coefficient of the liquid phase and to the non dimensional fluorescence efficiency.

The ratio of these powers provides the map of the Sauter mean diameter in the spray, $D_{32}(x,y)$, with a calibration constant of the imaging system that can be determined under references conditions (usually by comparison with PDA data in a diluted spray).

The key points of the Planar Droplet Sizing method are that both the local laser irradiance and the actual volume capacity of the probing disappear in the ratio. The method should be insensitive to the partial extinctions experienced by the different radiations in a dense spray. However attenuation of the radiation by elastic interactions is complementary accompanied by scattering and in dense sprays the consequences of multiple scattering on the measurement must be investigated. An other aspect investigated in the paper is the influence of anisotropy of coefficients α and β. Actually, even if laser induced fluorescence is basically a spontaneous isotropic emission process at molecular level, owing to the non uniformity of the laser irradiance within a liquid droplet (focusing effect of the curved interface) the global emergence of the fluorescence from a droplet is anisotropic.

The coaxial injector consists of a central pipe (Φ=2 mm) fed with water doped by a weak concentration of fluorescein (0.01g/l) flowing at 0.8 m/s. The liquid jet is destabilized and atomized by a parallel air flow issuing at 115 m/s from a thin annular duct. The laser radiation is provided by the third harmonic of a pulsed YAG laser (λ = 355 nm, Δt=10 ns, F=10 Hz) and focused into a vertical light sheet passing through the axis of the spray. Fluorescence and Mie scattering are collected at 90° of the laser plane and sent in a separator device. Using dichroic tilted mirrors and spectral filters this device induces a slight angular shift between the transmissions at 355 nm (Mie) and above 450 nm (Fluo.) so that two translated images of the spray are registered by the gated intensified CCD camera at each laser firing. 2500 pairs of pictures were registered and the mean noise level was subtracted. A test card was used to obtain the accurate pixel to pixel correspondence between the two pictures.

In the near development field of the spray the Mie scattering pictures are well symmetrical with respect to the flow axis whereas careful measurements show that the incident laser is significantly attenuated. Measurements and Monte Carlo simulations confirm that in a spray composed of large droplets for which elastic scattering is mostly concentrated forward in a small solid angle the Beer-Lambert extinction decay of the laser irradiance can be compensated by the cumulative contribution of multiple scattering.

On the other hand the radial profiles of laser induced fluorescence are asymmetrical with a surprising higher signal level on the side opposite to the laser as if the fluorescence efficiency was increasing with the propagation of the laser through the spray. When expressing the local power of the fluorescence induced under the same conditions as previously where multiple interactions are involved, in addition to the fluorescence induced by multiple Mie scattering a third term should account for elastic scattering of the fluorescence. However simulations show that the contribution of this third term is negligible (in any case it should not be increasing with laser propagation since fluorescence from a droplet is emitted rather backward).

When excited by a plane wave the spherical interface of a drop focuses the laser irradiance into regions of high field at the internal caustic structure where saturation can lead to a global decay of the fluorescence directly induced by the incident laser. Now when excited by several incident waves with different directions as done by the contribution of multiple scattering, the irradiance in a drop is nearly homogeneous and the subsequent fluorescence emission is linearly induced. However Monte Carlo simulations indicate that this differential effect is still weak to explain the observed asymmetry of the fluorescence profiles when multiple scattering occurs.