DIAGNOSTICS OF OPTICALLY DENSE DUSTY PLASMA

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Analysis of radiative heat transfer in real dusty flows requires knowledge of the particle temperature and their optical characteristics such as the single scattering albedo, the phase function and the optical depth. These characteristics determine the emissive ability of scattering media and can be obtained from light transmittance measurements [1-5]. Most of the techniques for non-intrusive determining the particle sizes and optical properties rely on the Mie theory and use the Beer-Lambert (B-L) law. Measured extinction of light by particles, especially those larger the measurement wavelength, must be corrected for forward- scattered light collected by the detector. These corrections have been investigated in detail for single scattering [1]. The techniques developed on the base of the measurements of a forward angle scattering transmittivity (FAST) are used for the analysis of the particle sizes, concentration and real refractive index [2]. Some of the most difficult problems are the measurements in large optical depths when multiple scattering phenomena occur [3]. Corrections to the B-L law in the case of a detector with a variable field of view have been analyzed for turbid media by means of a small-angle solution to the radiative transfer equation [4]. Nevertheless the small angle approximation is valid only for large particles with highly-peaked scattering phase functions.

This work extends the application of FAST technique for turbid medium [6]. We derive forward multiple scattering correction factors as a function of a detector field of view by using lower estimations of the contribution of multiple scattering in forward- scattered light collected by the detector:

$$C_q \geq C_q^{\min} = \frac{\ln(1-C_t^{\min})}{q(\theta_d)\tau}, \tag{1}$$

where

$$C_t^{\min} = \frac{<\mu> s\tau\exp(-\tau)\{1-q(\theta_d)\}}{2(1-s)\exp\{-q(\theta_d)\tau\}}, \tag{2}$$

Here $s = wC_s\left\{1-\exp(-<\mu>\tau/2)\right\}$, and $C_s = \max\{<\mu>, q(\theta_d)\}$, $<\mu>$ is the asymmetry factor of the phase function $p(\theta)$, $w = \sigma_s/\sigma_{ext}$ is the single scattering albedo, and $q(\theta_d) = \tau^*(\theta_d)/\tau$, where τ is the true optical depth, τ^* is apparent optical depth measured by the detector at half aperture angle θ_d [1]. Then the value of the correction factor C_q can be expressed as

$$C_q = C_q^{\min} + \Delta\,. \tag{3}$$

In the event that the value of Δ can be neglected, the value of the correction factor C_q can be easily calculated from Eqs. 1-3. In the experimental part of this work, we compare the calculated values of $C_q^{\min}$ with the measured correction factor C_q and examine the application of $C_q = C_q^{\min}$ for correcting the measured relative cross section $q_{ms}(\theta_d)$:

$$q_{ms}(\theta_d) = q(\theta_d)(1 - C_q)\,. \tag{4}$$

The FAST instrument was described in [2]. The optical scheme of the instrument is shown in Fig. 1.

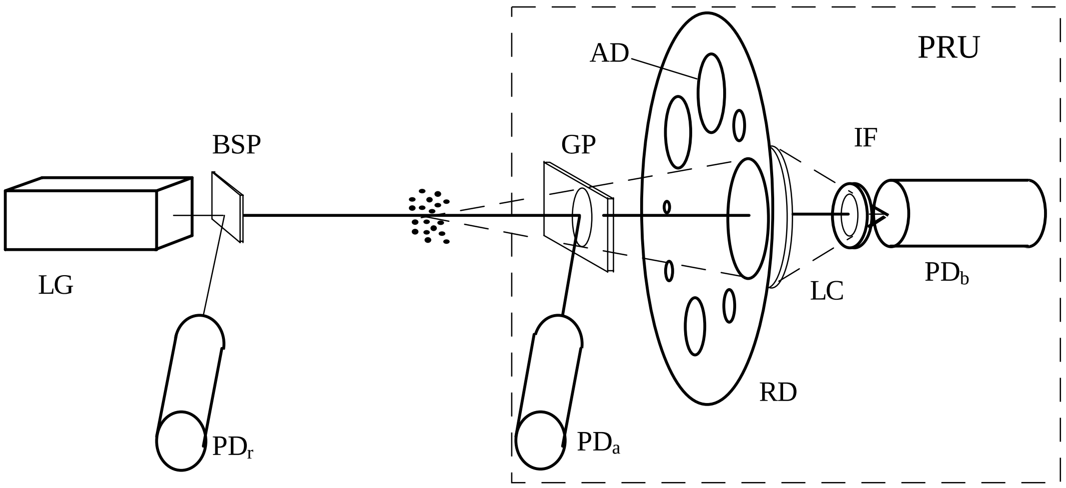

Fig. 1. The optical scheme of the FAST instrument.

The light source is a 50-mW Ar+-laser LG with a beam diameter of 1.4 mm and a beam divergence of 0.4 mrad. A set of eight diaphragms AD on a rotating circular disc RD is in front of the optical system LC. Transmitted light passes from the collection of particles to an aperture diaphragm which rejects that scattered at angles larger than aperture angle θ. Thus, radiation making an angle smaller than θ with the beam axis is sampled by photo-receiver unit PRU. The photo-receiver unit includes a lens condenser LC with a focal length of 100 mm and a diameter of 100 mm, narrow bandwidth filter IF, beam-splitter glass plate BSP, photodiodes PD_b and PD_a, and preamplifiers PA.

The unit also has two optical channels, the basic channel, and the auxiliary channel. The basic channel is used to detect the transmitted and scattered light passing through aperture diaphragms AD of different diameters (5.0, 7.6, 11.7, 17.3, 26.0, 39.5, 59.5, and 75.0 mm). The auxiliary one is used to detect the laser radiation passing through small diaphragm of diameter of 3 mm fixed in front of photodiode PDa. The auxiliary channel accounts for the effect of particle concentration fluctuations on the beam attenuation measured in the basic channel. The reference channel consists of small glass plate GP, and photodiode PDr. The glass plate diverts some of the emitted power, which is then used as a reference to enable laser radiation fluctuations to be taken into account.

The diaphragms are continuously scanned during the operation. The disk completes 10 rotations per 1 s. The ratio between digital signals at basic I_b and reference I_r channels I_b/I_r, and one between digital signals at auxiliary I_a and reference I_r channels I_a/I_r are measured. The result of the measurements are stored on a computer disk for preliminary processing. Then the angular distribution of $q_{ms}(\theta_d)$ function is obtained as

$$q_{ms}(\theta_d) = \frac{\ln[(I_b^o / I_r^o)/(I_b / I_r)]}{\ln[(I_a^o / I_r^o)/(I_a / I_r)]}, \tag{13a}$$

where subscript 0 denotes the signal measured when no particles are present in the medium. So, the variations of $q_{ms}(\theta_d)$ give extinction produced by spheres, regardless of power fluctuations of the source.

We test FAST technique for measuring transmission of the suspension of commercially calibrated polystyrene spheres in distilled water at the optical depths up to 6.

We examine the application of the obtained numerical estimations C_q for forward multiple scattering correcting the transmission measurements at the scattering angles $\theta_d < 6^o$. Measurements were carried out in turbid media for the short (5- mm), and long (200-mm) cells with suspended latex spheres. We conclude that the application $C_q^{\min}$ as a multiple scattering correction factor permits the use of FAST technique for determining the particle parameters at optical depths up to 5. With increasing length of cell (to 200-mm) the effect of multiple scattering is decreased, allowing measurement of particle particles at optical depths up to 3 without multiple scattering corrections.

References

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