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Scattering Effects in Laser Attenuation System for Measurement of Droplet Number Density

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Abstract

Laser attenuation system can be used to measure droplet number density in suspended particles including sprays, which are used in combustion studies. The system is also capable in determining the molar absorptivity of a liquid or solid medium. Nevertheless, any kind of light is known to experience scattering that is resulted from non-uniformity of the medium that the light passes through. In this paper the occurrence of light scattering in laser attenuation system for different medium is investigated. The laser attenuation system is developed and calibrated using commercial light filters of known densities. The occurrence of scattering and its significance is studied using iodine and water sprays. The study reveals that a total of about 13% of the light is scattered elsewhere.

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Keywords: attenuation; scattering light; sprays; number density

1. Introduction

Laser attenuation or light extinction technique has been long established mainly to measure properties of particles or aerosols by using the Beer-Lambert law [1]. It is an attractive technique because it provides an instantaneous, nonintrusive measurement. The basic principal of operation of laser attenuation can be found in various references, for example in [2]. When a body is crossed by a radiation beam, a portion of the incident flux Φ_i is reflected (Φ_r) at

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the entrance and exit surfaces, and another portion (Φ_a) is absorbed, while the remainder is transmitted. The ratio Φ_a/Φ_i is the extinction factor of the body or the absorption factor if absorption is the dominant phenomenon, and that all fluxes Φ_r, Φ_t and Φ_a, which arise from a monochromatic flux are precisely proportional to Φ_i. The technique was used in the study of aerosol size distribution, e.g. in [3], in a number of researches related to combustion of droplets [4-8], and was also employed for measurements of soot volume fraction in engine combustion [9-11]. In a more recent development, the light extinction technique has been studied for particle sizing [12].

Two main mechanisms by which energy can be removed from incident light traversing a medium are scattering and absorption. Scattering of lights by spherical particles that are larger than the wavelength of the light are referred to as Mie scattering. Dispersed air bubbles in water mainly scatter light, while absorption is neglected. Generally, the intensity distribution of the scattered light is proportional to the local number density and surface area of the particles [13]. The intensity of a collimated monochromatic laser beam traversing a dispersion of uniform spherical particles in a uniform medium attenuates and can be estimated using light extinction theory.

Light scattering is a problem in laser attenuation measurement for aerosols since the forward scattered light flux superimposes on the transmitted light flux thus resulting in error in the measurement results [14]. On the other hand the scattering effect is dependent on the geometry [15] of the measuring system and also the optical depth. Wind & Szymanski (2002) presented in their work that if the field of view is small, the scattering effect is negligible. The use of lens and pinhole was suggested to minimize forward scattering effect [16], but it was also pointed out that there would always be some scattering effect especially if the droplet size is larger than the laser source wavelength, λ. An ideal situation for the usage of laser attenuation method would be the use of extremely fine aerosol, e.g. 0.1 λ in order to get Rayleigh scattering. Larger particle experiences a sharper and more intense forward lobe of Mie scattering thus may cause higher measured light intensity than expected. Nevertheless, in many practical situations involving sprays, the droplet size is larger than the lasers' wavelengths, and thus light scattering could not be avoided.

There has been limited work to verify the accuracy of measurements by light extinction techniques; e.g. [15, 17]. In addition, the inherent limitations of estimating aerosol optical properties from bulk aerosol measurements were addressed, at least in part, by a number of authors. For example, from basic theoretical considerations it was showed [18] that if an aerosol is mixed externally or if in an internally mixed aerosol the index of refraction is not a function of composition or size, and the aerosol density is independent of volume.

The objective of the present work was to study the occurrence of and to quantify scattering lights in a laser attenuation system when applied in selected mediums. The study was conducted by measuring light intensities at various angles relative to the incident light. The experiments were conducted using low power laser that were passed through the mediums with a set of aligned optical system. Customized light intensity meters were used to measure the laser that passed through the medium.

2. Experiment Setup

Shown in Figure 1 is the optical setup for the light extinction experiments. During the experiments, the system was mounted on an aluminium platform for accurate positioning of optical components. The experiments recorded the average data for the whole field of view of the windows.

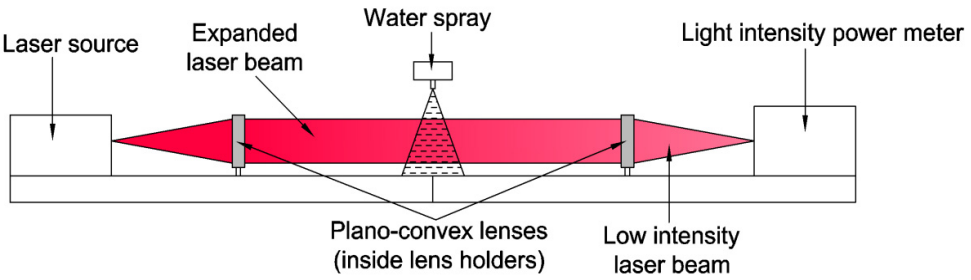

Fig. 1.Schematic of the light extinction system.