Effect of particle aggregation on soot temperature determination in two-color LII experiments

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Aggregation of soot particles results in mass fractal structure. It has been established that the particle aggregation makes the total absorption cross section of an aggregated soot particle deviate from the Rayleigh-Debye-Gans theory. This not only affects the ability of soot aggregates to absorb laser energy, but also their emissivity. This study investigates how aggregation affects the soot temperature derived from the signal ratio in two-color LII experiments.

Introduction

Increasingly research attention has been paid to the optical properties of fractal aggregates due to the fact that flame generated soot particles can be well characterized as mass fractal objects. Particle aggregations alter many physical and optical properties of soot compared to those of isolated, non-aggregated primary spherical particles. In the context of LII, it is important to quantitatively understand how aggregation affects the heat conduction behavior and the laser energy absorption rate of soot. Some efforts have been recently devoted to these aspects [1,2]. Since aggregation alters the absorption behavior of soot aggregates compared to that from the Rayleigh-Debye-Gans (RDG) theory, it is expected that their emission behavior is also changed accordingly. The emissivity of soot aggregates is required in the determination of soot temperature in two-color LII experiments, based on the ratio of LII signals detected at two wavelengths. However, the effect of aggregation on the soot temperature determination in two-color LII measurements has not been investigated. The objective of this study is to quantify the error of soot temperature caused by the neglect of aggregation effect.

Theory

For an arbitrarily shaped particle the emissivity is equal to its absorption efficiency [3]. Applying this principle to an aggregate leads to

$$Q_{abs}{}^{agg} = \varepsilon_p{}^{agg} \tag{1}$$

For an aggregate of size N, i.e., it consists of N primary spherical particles, its absorption efficiency is written as

$$Q_{abs} = C_{abs}{}^{agg} / (N A_{geo}{}^{p}) \tag{2}$$

where $C_{abs}{}^{agg}$ is the total absorption cross section of the aggregate and $A_{geo}{}^{p}$ is the geometric cross sectional area of a primary particle.

Two models were used to calculate the total absorption cross section of soot aggregates. One is the RDG theory for fractal aggregates and the other is the numerically exact generalized Mie-solution method (GMM). Aggregation effect is neglected in the RDG theory but is fully accounted for in the GMM results. GMM calculations were conducted for λ = 400 nm and 800 nm, d_p = 45 nm, and a constant refractive index of $m = 1.6 + 0.6i$ to represent a typical value of soot in the visible. Representative results are shown in Fig. 1. For a given signal ratio (400nm to 800nm) the corresponding temperature can deviate from that based on the RDG model by about 100 K. Such an error in the soot temperature can lead to larger error in the soot volume fraction in the absolute LII intensity method [4]. The effect of soot particle aggregation on soot emissivity should be accounted for in the determination of soot temperature in two-color LII measurements.

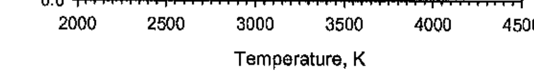

Fig. 1 Radiation intensity ratio from soot aggregates at 400 nm and 800 nm in the temperature range of 2000 to 4500 K for d_p = 45 nm and a constant refractive index m = 1.6 + 0.6i.

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