Dust-induced regulation of thermal radiation in water droplets

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Ⅰ. Introduction

Accurate and fast prediction of the thermal radiation properties of materials is crucial for their potential applications [1-3]. However, some models assume that the media are made up of pure water droplets, which do not account for the increasing deviations caused by volcanic eruptions, pollution, and human activities that exacerbate dust production [4-6]. The distinct radiation properties of water and dust particles make it challenging to determine the thermal radiation properties of water droplets containing dust particles. To address this issue, we investigate the influence of dust particles on light transmission and energy distribution in water droplets. Our results reveal the significant role of dust particles in the thermal radiation effect and provide insights into the electromagnetic properties of colloidal suspensions.

Ⅱ. Methods

For independent scattering particles with random orientation distribution and rotational axis symmetry, the dimensionless Stokes scattering matrix can be expressed as follows:

$$\begin{bmatrix} I^n \\ Q^n \\ U^n \\ V^n \end{bmatrix} = \begin{bmatrix} S_{11}(\Theta) & S_{21}(\Theta) & 0 & 0 \\ S_{21}(\Theta) & S_{22}(\Theta) & 0 & 0 \\ 0 & 0 & S_{33}(\Theta) & S_{34}(\Theta) \\ 0 & 0 & -S_{34}(\Theta) & S_{44}(\Theta) \end{bmatrix} \begin{bmatrix} I^m \\ Q^m \\ U^m \\ V^m \end{bmatrix} \quad (1)$$

where $[I_n, Q_n, U_n, V_n]^t$ and $[I_m, Q_m, U_m, V_m]^t$ are the Stokes vectors of the scattered waves and incident waves, respectively. S is the scattering matrix, and Θ is the scattering angle ($0^\circ < \Theta < 180^\circ$).

The extinction efficiency and scattering efficiency for spheres are shown as

$$Q_{\text{ext}} = \frac{2}{\chi^2}\sum_{n=1}^{\infty}(2n+1)\,\text{Re}\{a_n + b_n\} \quad (2)$$

$$Q_{\text{sca}} = \frac{2}{\chi^2}\sum_{n=1}^{\infty}(2n+1)\left[|a_n|^2 + |b_n|^2\right] \quad (3)$$

where a_n and b_n are the Lorenz-Mie coefficients, D is the diameter of spheres, λ is the wavelength.

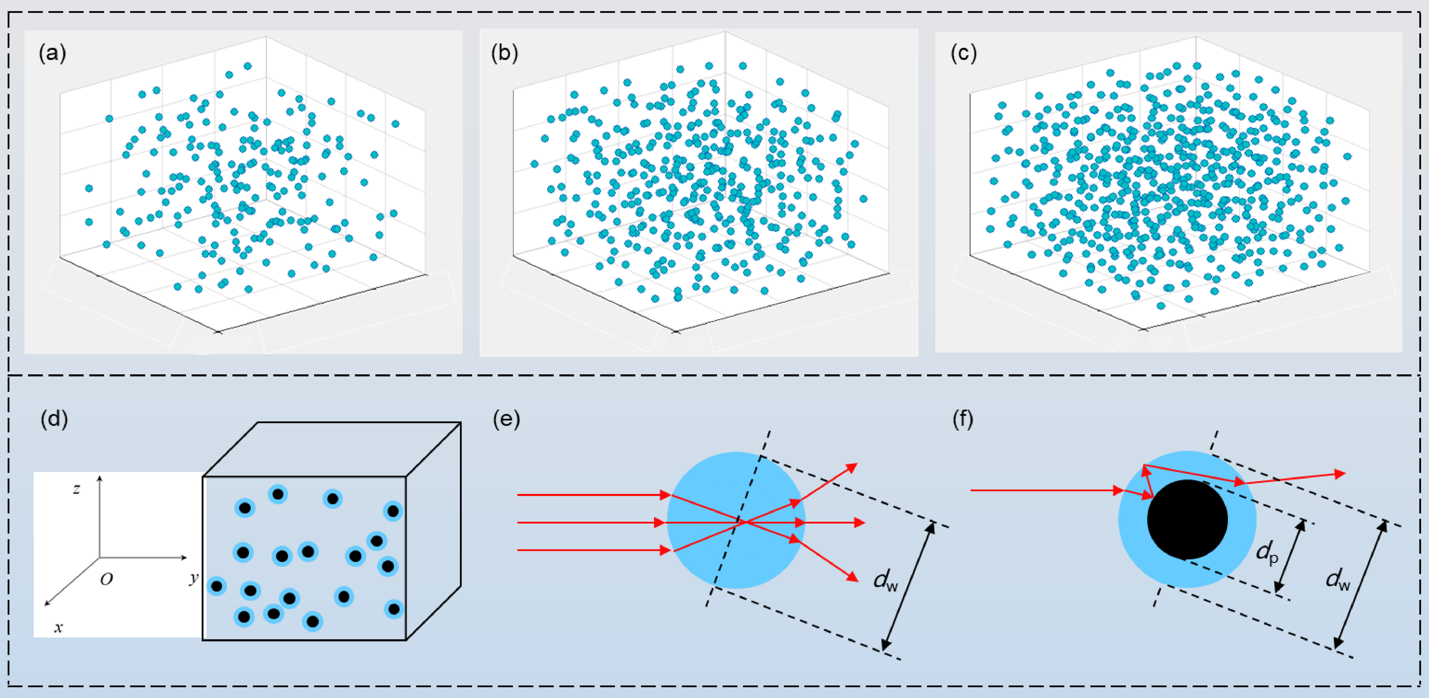

Fig. 1. Effect of water droplets and dust particles on light transmission. The distribution of water droplets with different volume fractions f_v is shown for (a) f_v = 10%, (b) f_v = 20%, and (c) f_v = 30%. (d) Water droplets containing dust particles in a cube with a side length of 20 mm. (e) Light transmission in pure water droplets. (f) Light transmission in water droplets containing dust particles.

III. Results

We examined the impact of dust on the regulation of thermal radiation in water droplets, with a specific focus on various factors such as the complex refractive index of dust, the diameters of both dust and water droplets, and the position distribution of dust and water droplets on the extinction coefficient of dust-containing water droplets.

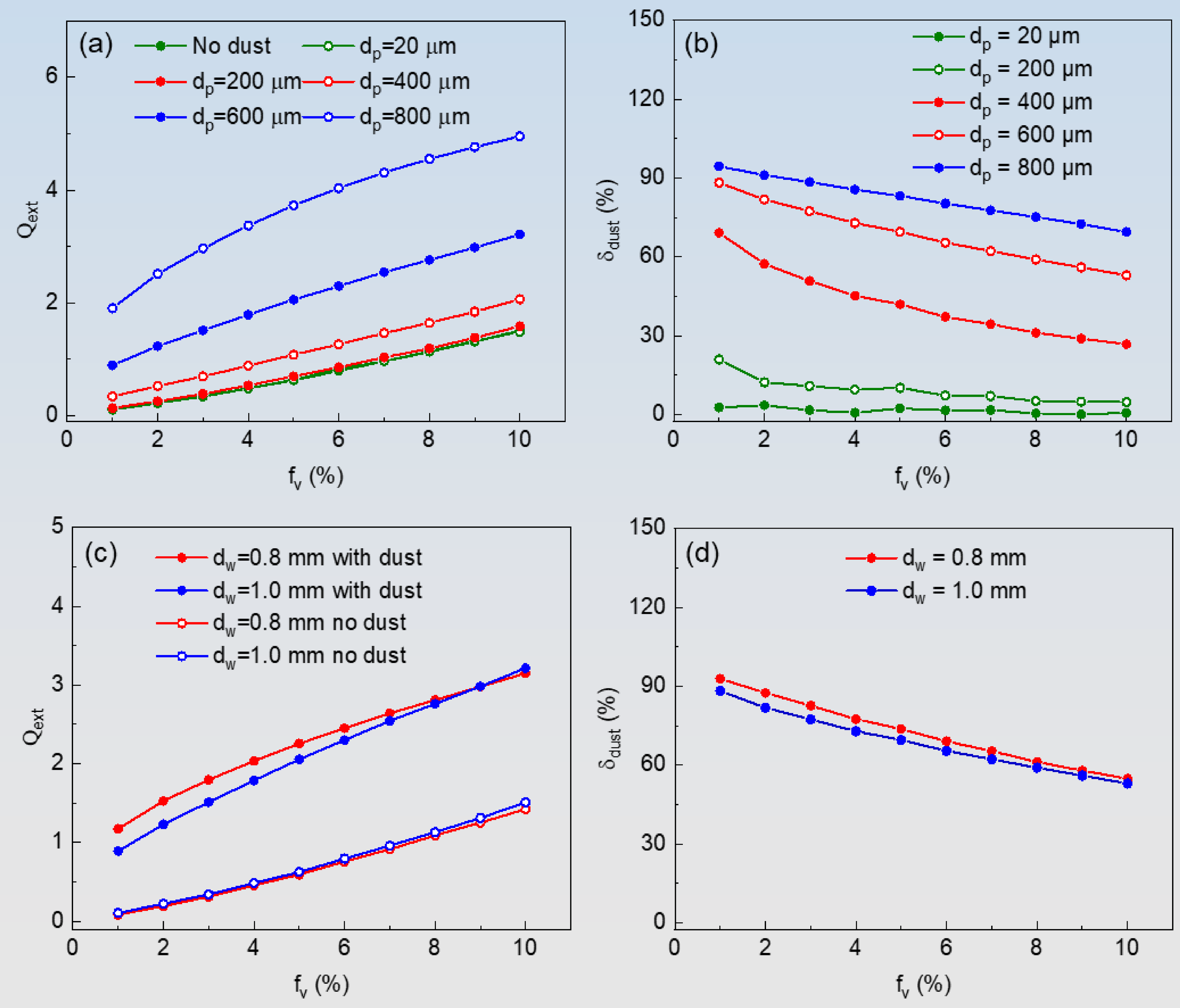

Fig. 2. Effects of diameter and complex refractive index on extinction efficiency. (a) Extinction efficiency versus volume fraction of water droplets, and (b) relative error versus volume fraction of water droplets for different diameters of dust particles d_p. (c) Extinction efficiency versus volume fraction of water droplets, and (d) relative error versus volume fraction of water droplets for different diameters of water droplets d_w.

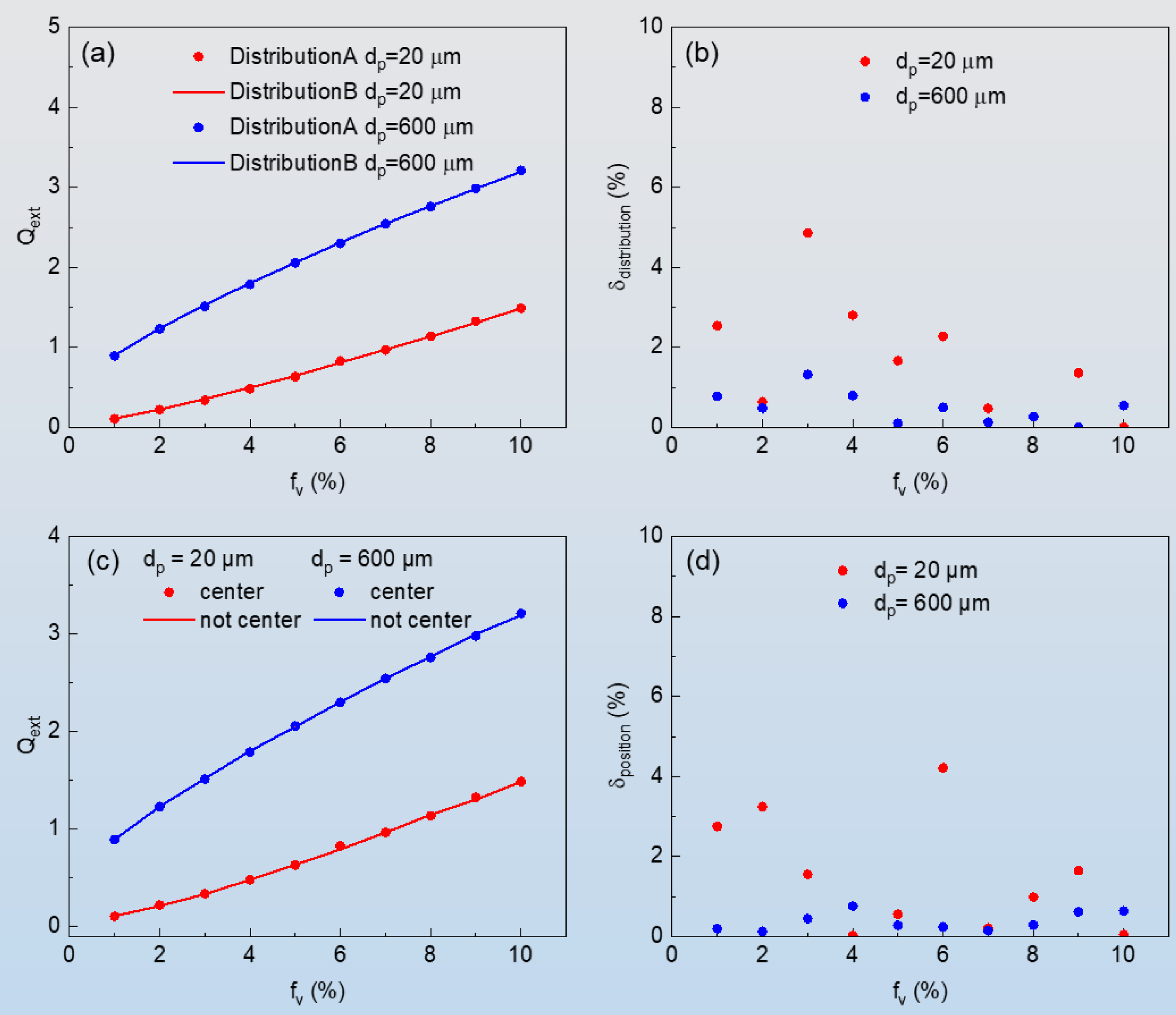

Fig. 3. Effects of position distribution on extinction efficiency. (a) Extinction efficiency versus volume fraction of droplets, and (b) relative error versus volume fraction of droplets for different positions of droplets. (c) Extinction efficiency versus volume fraction of droplets, and (d) relative error versus volume fraction of droplets for different dust positions in droplets.

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