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Electromagnetic scattering by fine ceramic spheres and scattering-induced suppression of insolation heating

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1.INTRODUCTION

The temperature of materials rises when they are exposed to the sunlight (insolation heating). Insolation heating could be suppressed when the materials are coated with paint admixed with fine silica spheres (insulating paint). By coating buildings walls and roofs with such paint, the temperature in rooms could be kept lower without air-conditioners. These phenomena are well known and have been utilized in the past, but have hardly been analyzed theoretically yet. Theoretical analysis could greatly enhance the effects of the suppression of insolation heating if we understand the mechanism of insolation. We focus on the light scattering by fine spheres assuming that the scattering attributes to the phenomena.

In this study, we consider fine silica spheres randomly distributed in a paint layer coating a material, and analyze its scattering characteristics using a Monte Carlo ray tracing method based on the Mie theory. We finally investigate how the structure of the paint attributes to the scattering characteristics.

2. METHOD

We assume three layers: air, paint, and iron that is coated with the paint. Fine spheres are randomly distributed in the paint layer by using Distinct Element method (DEM).

A number of photons comprising the light vertically incident to the paint at random coordinate from the air. We then count the total number of photons that reaches the iron and estimate the amplitude and the intensity of the transmitted light wave.

We use the Fresnel Equations to consider the reflection and the transmission effects. The reflection and the transmission coefficients are used to determine photons behavior stochastically using a random value. Moreover, the Mie theory was used to calculate the scattering distribution of sphere when photons incident to spheres.

3. RESULT

We calculated the transmission intensity distribution associated with two factors: the size parameter of the sphere (the ratio between sphere radius and incident wavelength) and the contrast between the refraction coefficients of the paint and spheres.

The transmission intensity decreases as the contrast becomes larger or as the sphere radius becomes smaller. These phenomena are observed due to the characteristics of the Mie scattering, i.e., (a) the scattering cross section of a sphere becomes larger simultaneously with the contrast and (b) the backscattering becomes dominant when the size parameter of the sphere got smaller.

Furthermore, the local minimum values are observed on a specific wavelength band when a sphere radius is given. It therefore indicates that the specific wavelength band could be selectively weakened depending on the appropriate chosen sphere radii.

4.Summary

Our goal is to analyze the light scattering to find the most efficient structure of the scatterer. We calculated the total intensity of transmitted waves assuming that fine silica spheres are randomly distributed in a paint layer.

For effective insulating paint, it is found that the sphere radius should be less than 1.0um and the refractive index of sphere is less than 1.5 or more than 1.7 if we want to decrease the transmission intensity to less than about 0.2-0.3. Moreover, the distribution of the transmission intensity does not show monotone increase/decrease but shows peaks and troughs in these results. Thus, there could be an optimum sphere radius and an optimum material of spheres with respect to improving the effects of the insulating
paint.

Keywords: scattering, electromagnetic wave, ceramic sphere, Mie scattering, energy saving, insolation heating