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RADIATIVE HEAT TRANSFER IN PARTICULATE MEDIUM: METHODS, METRICS AND REVISED REGIME MAP

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ABSTRACT Radiative transfer in media consisting of randomly dispersed particles is commonly found in various scientific and engineering applications. Radiative transfer equation is used for modelling such engineering systems, where radiative transfer properties are estimated considering independent scattering approximation due to its simplicity. This approximation is based on representing properties in terms of superposition of individual particles' contributions and it is valid for sparsely distributed particles. For denser systems, the scattered fields of neighbouring particles might interfere with each other that is known as the far field effect and the internal EM fields within the neighboring particles can also effect each other, that in turns effect the scattered intensity that is known as the near field effect. The combination of these two phenomena is referred as dependent scattering and the radiative properties deviate from those predicted based on independent scattering approximation in presence of dependent scattering effects. As considering dependent scattering effects requires a more rigorous analysis, identification of the scattering regime is important, which is carried out by utilizing established regime maps developed in the 1980s.

It was recently shown experimentally that the validity of the regime map is questionable at some regions, and this triggered recent efforts on re-evaluation of scattering regime map. While most of these studies rely on various Maxwell's equation solvers, they suffer from two major issues. Although modern computers are more capable than those of 1980s, solving Maxwell's equations for large systems still possesses a great challenge, which limits the analysis to systems of finite number of particles. First issue observed in some of the studies is that the number of particles considered are not adequate to represent an ergodic system. Whereas, in the studies, where systems of larger number of particles are considered; the analysed systems consider interaction of incident wave from a free space with particles typically within a well defined system boundaries, which introduces a coherent scattering effect at the boundary of the system analysed. This effect is not present in an infinitely large particulate system, where incoherent component of the scattered field must be considered as it represents the scattering of electromagnetic waves propagating through a dense infinitely large medium. Therefore, for such systems the scattered field must be split to its coherent and incoherent components and the incoherent component must be considered for representing the scattering behaviour. The second issue observed is that all the studies considering relatively large number of particles have considered total scattered field in their analysis rather than the incoherent field. Overseeing the presence of coherent scattering in their analysis leads to an overestimation in the scattered field and erroneous conclusions.

In this talk our group's recent work on identifying the proper methodology and metrics for evaluating the regime map is presented. It is shown that radiative transfer through a dense dielectric particulate

medium can be modelled using Monte Carlo method for solving radiative transfer equation, where radiative transfer properties can be estimated using the Lorenz-Mie theory corrected with static structure factor for accounting dependent scattering effects. This approach is extensively validated against experimental data and exact solutions of Maxwell's equations using Tmatrix method. It is found that this approach has certain benefits to solving Maxwell's equations for a study for establishing a regime map. It is also shown that rather than scattering coefficient, scattering phase function or asymmetry parameter used in the recent literature, transport scattering coefficient that correlates well with reflectance, can be used as a single intrinsic characteristic to define the transition between the independent and dependent scattering. Utilizing the identified methods and metrics, a revised regime map has been identified, considering the effects of particle size distribution and medium properties. While the revised regime map is mostly in agreement with the older map, it resolves the discrepancies between the old map and recent experimental data.