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The influence of anisotropic scattering on the radiative intensity in a gray, plane-parallel medium calculated by the DRESOR method

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Abstract

Even though there have been many ways to treat complex anisotropic scattering problems, in most of the cases only the radiation flux or its dimensionless data were provided, and radiative intensity with high directional resolution could merely be seen. In this paper, a comprehensive formulation for the DRESOR method was proposed to deal with the anisotropic scattering, emitting, absorbing, plane-parallel media with different boundary conditions. The method was validated by the data from literature and the integral formulation of RTE. The DRESOR value plays an important role in the DRESOR method, and how it is determined by the anisotropic scattering was demonstrated by some typical results. The intensities with high directional resolution at any point can be given by the present method. It was found that the scattering phase function has little effect on the intensity for thin optical thickness, for example, 0.1. And there is the largest boundary intensity for the medium with the largest forward scattering capability, and the smallest one with the largest backward scattering capability. An attractive phenomenon was observed that the scattering of the medium makes the intensity at boundary can not reach the blackbody emission capability with the same temperature, even if the optical thickness tends to very large. It was also revealed that the scattering of the medium does not mean it cannot alter the magnitude of the energy; actually, stronger scattering causes the energy to have more chance to be absorbed by the medium, and indirectly changes the energy magnitude in the medium. Finally, it is easy to deduce all the associated quantities such as the radiation flux, the incident radiation and the heat source from the intensity, just as done in literature.

Keywords: Radiative transfer equation; DRESOR method; Monte Carlo method; Anisotropic scattering; Angular distributions of intensity

1. Introduction

The radiative heat transfer of particles cloud as well as the radiation of combustion gases–particles mixtures plays a significant role in many areas and devices. Some of them are pulverized-coal furnaces, cement kilns, fluidized beds and rockets with aluminized solid propellants. It is well known that anisotropic scattering is

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Nomenclature

A_n	coefficient for the nth-exponent Legendre polynomial
C_0	compensating factor, m^{-3}
D	distance, m
E_0	relative energy of energy rays
e	relative error of intensity
G	incident radiation, W/m^2
g	asymmetry factor for scattering
I	radiative intensity, $W/(m^2\,sr)$
I_R	radiative intensity got by the DRESOR method, $W/(m^2\,sr)$
L	thickness of the one-dimensional layer, m
M	number of discrete polar angles
N	number of discrete elements
N_0	number of energy rays used in the Monte Carlo method
P_n	nth-exponent Legendre polynomial
q	radiative flux, W/m^2
$\dot{Q}$	heat source, W/m^3
R_d^s	DRESOR values, m^{-2} or m^{-3}
$\mathbf{r}$	position vector
S	source function
$\hat{\mathbf{s}}$	direction vector
T	temperature, K
W	the whole surface area
κ	absorption coefficient, m^{-1}
σ_s	scattering coefficient, m^{-1}
β	extinction coefficient, m^{-1}
θ	polar angle $[0, \pi]$
θ_s	scattering angle $[0, \pi]$
φ	azimuthal angle $[0, 2\pi]$
ω	scattering albedo
ρ	reflectivity
ε	emissivity, relative radiative intensity
τ	optical thickness
Ω	solid angle
Φ	scattering phase function

Subscripts

η	discrete direction
j, j_0	discrete grid
new	new value after updating
old	old value before updating
w	wall
x, y, z	rectangular coordinates

usually a basic feature in high-temperature systems, and computation of multidimensional radiative transfer in an anisotropic scattering medium requires large amounts of computing time.

There are many ways to treat complex anisotropic scattering problems. Chui et al. [1] presented results by the Finite Volume Method (FVM) with the delta-Eddington scattering phase function in an axisymmetric