JOURNAL OF THERMOPHYSICS AND HEAT TRANSFER
Vol. 16, No. 3, July–September 2002

Three-Dimensional Discrete Ordinates Method in Transient Radiative Transfer

Zhixiong Guo*
Rutgers University, Piscataway, New Jersey 08854
and
Sunil Kumar†
Polytechnic University, Brooklyn, New York 11201

A complete transient three-dimensional discrete ordinates method is formulated for the first time to solve transient radiative transfer in a rectangular enclosure containing nonhomogeneous media that absorb, emit, and scatter. Twofold validation of the transient method is obtained: First, there is an excellent agreement between its results at long time stage with several steady-state solution methods. Second, the transient predictions of transmittance and reflectance compare very well with Monte Carlo simulations. The sensitivity and accuracy of the transient method against the sizes of time increment and grid cell and angular discrete order are examined. The false radiation propagation and numerical diffusion associated with the differencing schemes are discussed. Calculations show the behavior of the wave nature of propagation of transient radiation. The transient behavior of radiation is found to be influenced by many parameters, such as the boundary conditions, the optical thickness of the medium, the scattering albedo, and the incident radiation pulse width. Duhamel's superposition theorem is also applied to obtain the transient response to different temporal input pulses.

Nomenclature

A	=	area
c	=	speed of light
E_b	=	blackbody emissive power
G	=	incident radiation
$H(t)$	=	Heaviside unit step function
I	=	radiation intensity
L, H, W	=	length, height, and width
N	=	angular discrete order in S_N approximation
n	=	number of angular discretization
Q	=	radiative heat flux
R	=	reflectance
$\mathbf{r}$	=	position vector
S	=	source term
T	=	transmittance
t	=	time
t_p	=	pulse width
V	=	volume
W	=	angular weight
x, y, z	=	space coordinates
γ	=	weighting factor
Δt	=	time step
Δx	=	grid size
ξ, η, μ	=	direction cosines
ρ	=	reflectivity
σ_a	=	absorption coefficient
σ_e	=	extinction coefficient
σ_s	=	scattering coefficient
Φ	=	scattering phase function
ω	=	scattering albedo

Subscripts

d	=	downstream
P	=	control volume index
u	=	upstream
w	=	wall

Superscripts

l	=	control angle index
$*$	=	dimensionless quantity

Received 23 March 2001; revision received 14 June 2001; accepted for publication 11 March 2002.

*Assistant Professor, Department of Mechanical and Aerospace Engineering.
†Associate Professor and Othmer Senior Fellow, Department of Mechanical Engineering, 6 Metrotech Center; skumar@poly.edu. Senior Member AIAA.

I. Introduction

INTEREST in the study of transient radiative transfer has been increasing in recent years mainly because of the applications of short pulse lasers in a variety of engineering and biomedical problems, such as laser ablation,[1] optical tomography,[2] laser–tissue interaction,[3] laser material processing of microstructures,[4] and others. The transient nature of radiation transport in such applications is introduced via the inclusion of time derivative in the radiative transfer equation that accounts for the speed of radiation propagation. Some unique features associated with the transient radiation are being exploited and becoming well known, such as the thermal wave induced by pulsed laser heating[5] and the broadening of reflected and transmitted pulses after a laser pulse passes through a scattering medium.[6] Besides these emerging technologies, transient radiative transfer is also of significant in traditional applications, for instance, in astrophysical radiation hydrodynamics,[7] where the physical domain is very large. Note that the transient radiative transfer in the present study includes not only the transient boundary conditions as is done in the traditional concept of transient transfer,[8] but most important, it also incorporates the effect of radiation propagation speed in the governing equations.

The transient effects due to the speed of radiation propagation are only important for times of the order the characteristic time of travel of radiation along a characteristic path length within the geometry under consideration. A typical order of magnitude of this characteristic time can be estimated by dividing the characteristic length with the speed of propagation (which is the speed of light in the particular medium). For applications such as tissues where the characteristic length varies from few millimeters to dozens of