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# Analysis of combined conduction and radiation heat transfer in presence of participating medium by the development of hybrid method

S.K. Mahapatra[a,*], B.K. Dandapat[a], A. Sarkar[b]

[a] *Mechanical Engineering Department, University College of Engineering, Burla, Orissa, India*
[b] *Mechanical Engineering Department, Jadavpur University, Kolkata, India*

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**Abstract**

The current study addresses the mathematical modeling aspects of coupled conductive and radiative heat transfer in the presence of absorbing, emitting and isotropic scattering gray medium within two-dimensional square enclosure. A blended method where the concepts of modified differential approximation employed by combining discrete ordinate method and spherical harmonics method, has been developed for modeling the radiative transport equation. The gray participating medium is bounded by isothermal walls of two-dimensional enclosure which are considered to be opaque, diffuse and gray. The effect of various influencing parameters i.e., radiation–conduction parameter, surface emissivity, single scattering albedo and optical thickness has been illustrated. The adaptability of the present method has also been addressed.
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*Keywords:* Spherical harmonics method; Discrete ordinate method; Finite volume method; Isotropic scattering; Square enclosure; Gray medium

## 1. Introduction

The transport of thermal radiation is an important mechanism of energy transport in numerous engineering applications. The constitutive medium in majority of these systems actively participates in the radiative transfer due to absorption, emission, and scattering of radiation. Examples are abundant, notably fluidized bed combustion, insulation systems, particulate solar collectors and combustion systems such as furnaces containing fly ash, coal particles, soot agglomerates, etc.

Due to the difficulty in finding the exact analytical solution to integro-differential radiative transfer equation (RTE) in radiatively participating media, a diversity of numerical methods have been worked out over last few decades. Monte-Carlo (MC) technique, zonal method, spherical harmonics method, discrete ordinate method are few established methods which are also not free from limitations. Researchers found the

*Corresponding author. Qrs No. 3R/32, Professor Colony, Burla Engineering College Campus 768018, Orissa, India. Tel.: +91 9437257967; +91 6632430204.

*E-mail address:* swarupkumar_m@yahoo.com (S.K. Mahapatra).

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**Nomenclature**

| | |
|---|---|
| $A_W$, $A_E$, $A_S$, $A_N$ | four face areas (West, East, South, North) |
| $H$ | characteristic length [m] |
| $I$ | radiation intensity [W/m$^2$] |
| $I_b$ | black body radiation intensity ($=\sigma T^4/\pi$) |
| $k$ | thermal conductivity [W/mK] |
| $Q$ | dimensionless heat flux |
| $Q_T$ | total heat flux |
| $q_r$ | radiative heat flux |
| $q_c$ | conductive heat flux |
| $RC$ | radiation–conduction parameter ($=\sigma T_H^3 H/k$) |
| $T$ | absolute temperature [K] |
| $T_H$, $T_C$ | hot and cold wall temperatures |
| $w_i$ | quadrature weight associated with in any direction $s_i$ |
| $X$, $Y$ | dimensionless co-ordinate |

*Greek Symbols*

| | |
|---|---|
| $\alpha_a$ | absorption coefficient [1/m] |
| $\alpha_s$ | scattering coefficient [1/m] |
| $\beta$ | extinction co-efficient ($=\alpha_s+\alpha_a$) |
| $\Omega$ | solid angle [sr] |
| $\sigma$ | Stefan Boatsman's constant [$5.67\times10^{-8}$ W/m$^2$/K$^4$] |
| $\varepsilon$ | wall emissivity |
| $\xi$, $\eta$ | $X$ and $Y$ direction cosines |
| $\omega$ | single scattering albedo ($\alpha_s/\beta$) |
| $\rho$ | reflectivity of the surface |
| $\tau$ | total optical depth ($=\beta H$) |
| $\theta$ | dimensionless temperature ($T/T_H$) |

*Subscripts*

| | |
|---|---|
| c, R | conduction transfer, radiation transfer |
| H, C, L | hot wall, cold wall, bottom wall |
| w, m | wall, medium |

possibility of radiation modeling with Monte-Carlo technique for any participating medium with any desired radiative feature even though it is subjected to computational expense. In this regard, the work of Buckius [1] addresses the improvement in the computational time by using reverse MC technique. The account of non-homogeneity, non-isothermal, reflecting boundaries, an-isotropic scattering has also been addressed in the work. Yuen and Takara [2] has laid down the concept of superposition of fundamental principles in a gray-walled, two-dimensional rectangular enclosure with gray absorbing, emitting, isotropic scattering medium to find the temperature and heat flux distribution. The conventional zonal method has been employed in his work. The total exchange area method described by Hottel and Sarofim [3], and its variant in the work of Noble [4] and Larson [5] is another advanced superposition technique, found to be valid even in multi-mode heat transfer. Direct superposition is not valid in these non-linear situations whereas the total exchange area method finds its application with computational inefficiency.

Among the many numerical methods of solving RTE, the discrete ordinate method is considered a potential and a very promising tool, which transforms RTE into set of simultaneous partial differential equation.

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