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Application of the modified discrete ordinates method with the concept of blocked-off region to irregular geometries

H. Amiri [a,*], S.H. Mansouri [a], P.J. Coelho [b]

[a] Mechanical Engineering Department, Shahid Bahonar University of Kerman, Kerman, Iran
[b] Mechanical Engineering Department, Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

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ABSTRACT

The standard discrete ordinates method (SDOM) produces anomalies caused by ray effects if the temperature of the walls has discontinuities or abrupt changes. Ray effects may be mitigated using the modified discrete ordinates method (MDOM), which is based on superposition of the solutions obtained by considering separately radiation from the walls and radiation from the medium. The MDOM has been used to calculate radiative heat transfer in irregular geometries using body-fitted coordinates. Here, the blocked-off region concept is used along with the MDOM to solve radiative transfer problems in irregular geometries. Two-dimensional irregular enclosures with curved boundaries, obstacles or radiation shields and containing a participating medium are considered. The accuracy of the results calculated using the SDOM and the MDOM is assessed by comparing the predictions with those obtained by other researchers. The results confirm the capability of the MDOM to minimize the anomalies due to ray effects in various situations. It is concluded that the blocked-off region concept can be recommended as a good option to solve radiative transport problems in irregular geometries.

1. Introduction

Radiative heat transfer is important in many engineering applications and is often the dominant mode of heat transfer. Almost all practical situations involving radiative heat transfer occur in complex geometries, e.g., furnaces, boilers, combustion chambers, gas turbine combustors, spacecrafts and greenhouses, to name only a few.

Exact analytical solutions of the radiative transfer equation (RTE) in general absorbing, emitting and scattering media are exceedingly difficult and explicit solutions are impossible for all but the simplest situations. Therefore, several numerical methods have been developed for radiative heat transfer problems including the zonal, Monte Carlo, spherical harmonics, discrete transfer, discrete ordinates, finite volume, finite element and ray tracing methods.

The standard discrete ordinates method (SDOM) [1,2] has received significant attention and development due to its good accuracy, flexibility and moderate computational requirements. It can be applied to non-isothermal, non-homogeneous, anisotropically scattering, and non-gray media in complex geometries. However, the SDOM suffers from ray effects and false scattering. Ray effects are related to the discretization of the angular distribution of the radiation intensity, while false scattering is related to the spatial discretization of the RTE. Although the origin of the two errors is different, Coelho [3] showed that there is an interaction between them, and decreasing one of the errors while keeping the other unchanged may decrease the solution accuracy, because the compensation effect disappears. Chai et al. [4] proposed and discussed some remedies to overcome these two problems. False scattering may be reduced by refining the grid or by using more accurate differencing schemes [5,6]. Aiming at reducing the ray effects, several quadratures have been proposed, e.g. [7,8], and the modified discrete ordinates method (MDOM) was developed [9,10]. The MDOM proved to significantly mitigate ray effects originated from discontinuities or abrupt changes of the wall temperature. Originally developed for rectangular enclosures, it was later extended to enclosures of complex geometry [11,12], using the zonal or Monte-Carlo method to compute the in-scattering term related to the radiation intensity leaving the walls.

Due to the complexities in solving the RTE, its applicability to irregular multi-dimensional problems is always a challenging task. Various types of grid topologies such as curvilinear, body-fitted, multi-block, blocked-off, and embedded boundary grid systems have been successfully applied to simulate radiative heat transfer in complex geometries [12–17]. The MDOM has also been applied to radiative heat transfer problems in two-dimensional irregular enclosures using body-fitted grids [6,11].

* Corresponding author.
E-mail addresses: hosseinamiri2010@gmail.com (H. Amiri), mansouri@alum.mit.edu (S.H. Mansouri), pedro.coelho@ist.utl.pt (P.J. Coelho).

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