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Discrete transfer method with the concept of blocked-off region for irregular geometries

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Abstract

The discrete transfer method (DTM) is applied to irregular geometries with a concept of blocked-off region previously applied in the problems of computational fluid dynamics. This gives a new alternative to the DTM for its implementation to irregular structures. The Cartesian coordinate-based ray-tracing algorithm can be applied to the geometries with inclined or curved boundaries. Some test problems are considered and results are validated with the available results in the literature. Both radiative and non-radiative equilibrium situations are considered. The medium is assumed to be both participating and non-participating. Results are found to be accurate for all kinds of situations.

Keywords: Discrete transfer method; Participating media; Radiation; Blocked-off region concept

1. Introduction

Radiative heat transfer plays a dominant a role in many of the high-temperature applications as in combustion chambers, nuclear fusion, greenhouses, rocket plume sensing, etc. Due to the complexities in solving the radiative transfer equation, its applicabilty to multi-dimensional problems is always a challenging task. There are limited numbers of literatures available dealing with the radiative transfer problems with complex 2D and 3D geometries.

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Sanchez and Smith [1] discussed the radiative exchange of a square geometry with a square obstacle at the middle using the discrete ordinates method for a non-participating media. In participating media, Chai et al. [2,3] discussed different possibilities of solving radiative transfer problems in irregular structures using the discrete ordinates method, the finite volume method and the Monte Carlo method. They implemented blocked-off region procedure in the discrete ordinates method [2] and the finite volume method [3] for different types of irregular structures. They applied the Monte Carlo method [4] for irregular geometries and considered a rhombus, a quadrilateral and an enclosure with curved and straight edged boundaries. The medium considered was absorbing, emitting and anisotropically scattering. They also implemented the finite volume method in curvilinear coordinate with multiblocking to handle irregular geometries. Recently, Talukdar et al. [5] implemented the finite volume method in curvilinear coordinate with multiblocking for 3D irregular geometries. Murthy and Mathur [6] worked with unstructured meshes to implement the finite volume method for different complex geometries. Koo et al. [7] studied the effect of three different discrete ordinates methods applied to 2D curved geometries. In another paper, Koo et al. [8] discussed the first-order and second-order interpolation scheme in context with the irregular geometries. Sakami and Charette [9] discussed a modified discrete ordinates method based on triangular grids with a new differencing scheme applicable to different complex geometries. They intended to eliminate the ray effect inherent with the discrete ordinates method breaking the intensity into two parts: the wall-related intensity and the medium-related intensity.

The discrete transfer method (DTM) as founded by Shah [10] has been implemented to irregular structures by some of the works in the past. Meng et al. [11] used the DTM for irregular geometries using a finite element formulation. Malalasekera and James [12] applied the DTM for 3D irregular geometries using non-orthogonal body-fitted coordinate system. Malalasekera and Lockwood [13] also used the DTM in conjunction with a cell-blocking procedure based on Cartesian coordinate to model combustion and radiative heat transfer in complex 3D tunnel geometry.

In the present work, the blocked-off region procedure is implemented to the DTM. The concept of blocked-off region was previously applied in the computational fluid dynamics (CFD)[14] problems. As mentioned before, in radiative heat transfer, Chai et al. first implemented this concept with the finite volume method [3] and the discrete ordinates method [2]. They found very promising results for different 2D problems. Looking to the prospect of this concept, the current work tries to demonstrate its applicability to the DTM. As mentioned before, the DTM has been widely used for variety of problems. Being a ray-tracing method, the blocked-off region procedure is straight forward to implement in case of this method. The Cartesian based 2D algorithm can be used to calculate radiative fluxes for irregular geometries by dividing the region into active and inactive regions. It is easier and convenient way of handling 2D irregular geometries than to write an algorithm in curvilinear coordinates for a ray tracing method. The present work demonstrates the applicability and usefulness of the DTM with the current approach.

2. Formulation and solution procedure

In this section, the basic equations of the DTM used in this work are discussed and the solution strategy is explained.