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The finite volume method approach to the collapsed dimension method in analyzing steady/transient radiative transfer problems in participating media☆

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ABSTRACT

With the finite volume formulation (FVM) approach applied to the collapsed dimension method (CDM), this article deals with the application of the CDM to analyze radiative heat transfer problems in a participating medium subjected to a continuous diffuse or a continuous/short-pulse collimated boundary radiative loading. The planar medium contained between diffuse gray boundaries is absorbing, emitting and anisotropically scattering. With three categories of thermal boundary radiative loadings, for the four types of problems considered, the CDM results are compared for a wide range of radiative parameters with that of the FVM.

1. Introduction

Analysis of radiative transport in a participating medium finds applications in the thermal analysis of heat exchanges, boilers, furnaces, insulations, etc. [1]. It also finds applications in atmospheric science to estimate radiation budget and in biomedical science to diagnose tumors and in performing laser surgery [2].

Because of the volumetric phenomenon and angular dependence of the intensity, analysis of radiative transport in a participating medium is complex. Many numerical radiative transfer methods such as the Monte Carlo method, the discrete ordinates method (DOM), the discrete transfer method (DTM), the collapsed dimension method (CDM) and the finite volume method (FVM) are available to analyze radiative transport in a participating medium. Of the available method, the FVM [3] is the robust of all. By taking advantage of the DOM, it reduces the ray effect and false scattering by integrating intensities over the elemental solid angles. Further, like the FVM of the computational fluid dynamics, the FVM for radiative transfer is suited to any type of grid structure. Accordingly, the FVM is finding increasing applications in heat transfer problems involving thermal radiation.

Unlike the DTM, the DOM and the FVM in which radiation at a point is received from a 3-D spherical space, to make radiative intensity less dependent on angular dimensions, the CDM [4–9] collapses all information to a 2-D plane and then it views all phenomena in the 2-D space. This collapsing of information gives some advantage over the coding as well as computational time, as the CDM deals with one angular dimension less than the other methods. This concept of the CDM has been applied and tested by solving a large class of problems [4–9] in 1-D and 2-D rectangular geometries.

Originally the CDM [4–7] has been based on a ray tracing approach similar to the DTM. A ray tracing approach has a disadvantage that the procedure becomes very complicated and time consuming when the geometry becomes complex. To take the CDM a step ahead, Mishra et al. [8] applied the DOM concept to the CDM and successfully solved radiative transport problems in 2-D rectangular as well as trapezoidal geometries. Because of the reduced ray effect and false scattering, and owing to its adaptation to any grid structure, the FVM [3] is a superior method. Although the CDM so far has been applied to a large class of problems [4–9], to make its approach more attractive, the present work is aimed at implementing the FVM formulation to the CDM. Further, so far, the CDM has not been applied to analyze radiative transport problems dealing with collimated radiation. Thus, the objective of the present work is also to analyze a new class of problem with the CDM. When the radiation source is a short-pulsed, the radiative transport process becomes a transient one. With consideration of the time dependent term in the radiative transfer equation (RTE), solution becomes more difficult. Thus, the present work is also aimed at solving a pulse radiative transport problem using the CDM.

To test the application of the FVM approach to the CDM, we consider four different types of problems in a planar geometry. The

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