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Assessment of radiative property models in non-gray sooting media

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The radiative transfer equation (RTE) is solved by the Finite Volume Method (FVM) in 1D and 2D axisymmetric configurations containing mixtures of water vapor, carbon dioxide and soot. Several radiative property models, namely simple gray models, the Statistical Narrow Band Correlated-*k* (SNBCK) model, the Weighted-Sum-of-Gray-Gases (WSGG) model, the Full-Spectrum Correlated-*k* (FSCK) model, the Spectral-Line-Based Weighted-Sum-of-Gray-Gases (SLW) model, a Gray-Narrow-Band (GNB) model and a Gray-Wide-Band (GWB) model, are assessed by comparison with reference calculations based on the Ray Tracing (RT) method coupled with the Statistical Narrow Band (SNB) model. Different treatments of overlapping bands are implemented with the SNBCK model, namely the correlated approach, the uncorrelated approach, and the mixing schemes of Modest and Riazzi (J. Quant. Spectros. Rad. Trans. 90 (2005) 169–189) and of Solovjov and Webb (J. Quant. Spectros. Rad. Trans. 65 (2000) 655–672) (Superposition and Multiplication). The Full Spectrum (FS) *k*-distributions required to run both FSCK and SLW are assembled from the same narrow band (NB) database as for the SNB and the SNBCK models using either the mixing model of Modest and Riazzi or the Multiplication scheme. The correlated SNBCK is the most accurate model but is too time consuming for engineering applications. The computational efficiency of the SNBCK can be considerably improved without altering the quality of the solutions by using the gas mixing scheme of Modest and Riazzi. Numerical results show that, in this case, good accuracy for spectrally-integrated quantities is obtained by considering only a 2-point Gauss–Legendre quadrature scheme. The FSCK and the SLW, using FS *k*-distributions assembled with the Modest and Riazzi scheme, are found to be the best compromise in terms of accuracy and computational requirements. It is found that FSCK predictions remain satisfactory by reducing the number of quadrature points of the Gauss–Legendre scheme up to seven.

1. Introduction

The spread and growth of fires is mainly controlled by the heat transferred from the flame to the surrounding combustible materials through conduction, convection and radiation. It is well established that, in most practical applications, radiative heat transfer is the dominant mode of transfer [1]. The participating radiative species involve generally gaseous combustion products (CO_2, H_2O, CO, CH_4) and soot, the concentration of soot varying widely from one combustible to another. As a result the implementation of accurate radiative models in fire simulators is of fundamental interest.

The determination of accurate solutions for radiative heat transfer is difficult in media involving combustion products due to the strong dependence of the absorption coefficient of gases on the wavenumber. For example the line-by-line (LBL) method requires about 10^6 resolutions of the Radiative Transfer Equation (RTE) to consider this effect [2], involving computation requirements which are too large for practical applications. Various alternative gas property models have been developed or extended in recent decades to overcome this difficulty.

Narrow Band (NB) models, such as the Statistical Narrow Band (SNB) and the Correlated *k*-distribution (CK), have retained attention [2–6]. In particular, studies were conducted to establish new databases for these methods [5,6]. The accuracy of the SNB model, which gives the spectral transmissivity over a NB, is well recognized. However, this method suffers from two drawbacks. Firstly it cannot be easily coupled with differential solution methods of the RTE, such as the Discrete Ordinates Method (DOM) [7], the Finite

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