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High Accuracy, Computationally Efficient Modeling of Radiation Transfer in Gases

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Abstract

Radiation is a contributing and sometimes dominant mode of heat transfer in many gaseous applications, and its neglect in transport calculations can result in significant errors in predicted wall fluxes and local gas temperature. Rigorous prediction of the radiative transfer in gas mixtures at high temperature is extraordinarily difficult, owing to the highly complex spectral behavior of gases. The absorption/emission spectrum of real gases includes hundreds of thousands of narrow spectral lines whose strength varies by several orders of magnitude, and depends on radiating gas species and concentration, local temperature, and total pressure. This makes rigorous spectral integration of the Radiative Transfer Equation (RTE) in gas radiative transfer unusually challenging. Line-by-line spectral integration is possible, but tremendously expensive computationally, and is prohibitive in multidimensional and combined mode problems.

So-called global methods have been developed as engineering approaches to the prediction of radiative heat transfer in high-temperature gases. The first such global method to be proposed was the Spectral Line Weighted-sum-of-gray-gases (SLW) model, which reorders the complex highly oscillatory gas absorption cross-section into a smooth monotonically increasing distribution function. Simplistically, this model replaces integration of the RTE over wavenumber (or wavelength) by an integration over absorption cross-section. As a result, the number of integrations may be reduced from millions to just a handful. It has been found that the SLW model yields predictive accuracy within a few percent of the line-by-line solution but with computation time on the order of 10^{-5} that of the LBL solution. This presentation will briefly outline the theoretical complexities of predicting radiation in real gases. The fundamental concept behind the SLW model will then be outlined for situations of increasing difficulty ranging from single-component isothermal gas scenarios to multi-component systems with locally varying species concentrations and temperature. The model's application in select multimode heat transfer problems is illustrated.