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THE SCALED SLW MODEL OF GAS RADIATION IN NON-UNIFORM MEDIA

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Among the global methods of gas radiation, the Spectral-Line-Weighted-sum-of-gray-gases model (SLW) has been demonstrated to be a simple, yet an accurate and efficient method of spectral modelling of radiation transfer in gaseous media. The main challenge of global methods is spectral modelling of radiation transfer in non-uniform media (non-isothermal and/or non-homogeneous scenarios). Approaches based on the assumption of correlated gas absorption spectra have been developed. Greater accuracy among these approaches comes at the expense of greater sophistication, more complexity and difficulty in implementation, and higher computational cost. There is a need for simple, accurate engineering approaches for comprehensive modelling of heat and mass transfer. Recent progress in SLW modelling, including the development of the Generalized SLW model and the Rank Correlated SLW model, opens new opportunities for a scaled model. The scaled SLW model has never been explored, but it has potential to improve performance of the SLW method when correlated models fail.

In the scaled SLW model it is assumed that the absorption cross-sections of a particular gas or gas mixture at two different local thermodynamic states denoted symbolically as $\phi_1\left(T_1,Y_1,p\right)$ and $\phi_2\left(T_2,Y_2,p\right)$ are related by a simple scaling for the entire spectrum (over all wavenumbers $0<\eta<\infty$) as

$$C_\eta\left(\phi_2\right)=u\left(\phi_1,\phi_2\right)C_\eta\left(\phi_1\right)$$

The scaled spectrum assumption is a particular and more restrictive case of the correlated spectrum assumption. However, application of the scaled model may have some advantages. The correlated models rely on how well real spectra are correlated but they cannot overcome the fact that real spectra are never completely correlated. Consequently, in the case of highly non-uniform media the prediction of radiative transfer can be inaccurate. Scaled spectral models can improve performance with the help of a more specific choice of scaling coefficient $u\left(\phi_1,\phi_2\right)$ for better representation of gas absorption spectra at the local thermodynamic state in the prediction of radiative transfer in non-uniform media. At the same time, the scaled model is simpler in its construction and implementation, and it requires less computational effort. Computational economy is important when radiation is only a part of a comprehensive heat and mass transfer prediction.

Once the scaling coefficient is established, the scaled spectral model can be readily constructed. Therefore, the critical element of the scaled model is the method of calculation of an efficient scaling coefficient $u(\phi_1, \phi_2)$. A global scaled model requires the scaling coefficient for the entire (full) spectrum. However, for particular radiation problems, not all spectral regions contribute equally to the total radiation energy transfer. Emphasizing more important wavenumber regions by a properly chosen weighting function and requiring the scaling coefficient to preserve total characteristics of absorption coefficient at the local state can make scaling of some chosen reference spectrum to a spectrum at a local state more efficient.

This paper investigates different approaches for construction of the Scaled SLW model. Special attention is paid to explicit non-iterative methods of calculation of the scaling coefficient to maintain the SLW method as a simple and computational efficient engineering method. The moments of gas absorption cross-section weighted by the Planck blackbody emissive power (in particular, the first moment—Planck mean, and minus first moment—Rosseland mean) are used as the total characteristics of absorption spectrum to be preserved by scaling. Generalized SLW modelling of these moments (including both discrete gray gases and continuous formulation) and LBL look-up table for corresponding distribution functions (ALBDF and inverse ALBDF, ensuring that no solution of implicit equations is needed) ensures that the method is flexible and efficient.

Comparison of prediction of radiative transfer by the Scaled SLW model to LBL solutions and Correlated SLW models (Reference approach and Rank Correlated) is presented. Conclusions and recommendations on application of the Scaled SLW model are made.

References

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