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Impact of Solid Body Emissivity on Radiative Heat Transfer Efficiency in Furnaces – a Numerical Study

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Abstract

In this paper a theoretical approach is proposed and applied for quantifying the relevant radiation heat fluxes between the furnace walls, the internal surfaces and the flue gas. Numerical fluid dynamics calculations (CFD) are performed using a commercial code in which different wall emissivities are applied. To consider the spectral properties of the gas phase, the exponential wide band model (EWBM) was implemented into the CFD solver. Simulations results with a simplified gray radiation model and the EWBM clearly show that the simplified model leads to a considerable overestimation of the radiative heat transfer. Furthermore it can be shown, that for certain gas atmospheres the widely used gray radiation model is not suitable to identify the effect of high emissivity coatings on radiative heat transfer.

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1. Introduction

In many applications in chemical and thermoprocess industries gas phase radiation and solid body radiation are the predominant heat transfer processes due to the high temperature of the gas phase and the furnace walls. One objective within the context of furnace optimization and revision is to increase the efficiency of radiative heat transfer between the furnace walls and the materials or processes [1]. A common method to increase the radiative heat transfer is to increase the emissivity of the surfaces, which was subject of studies and praxis tests [1-3]. The

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selection of appropriate surface materials is a crucial design criterion. The spectral properties of the atmosphere between radiating surfaces is often not considered correctly which leads to significant errors, especially, when dependencies on wavelength and temperature cannot be neglected. To estimate the influence of increased solid body emissivities (i.e. due to high emissivity coating) on the efficiency of radiative heat transfer by using CFD analysis, it is essential to use advanced gas phase models, which are able to capture the spectral properties of the gas phase.

Absorption characteristics of gases are quite different from those of solids. Whereas gases like N_2, O_2 do neither absorb nor emit heat, combustion products like CO_2 and H_2O do over discrete wavelength intervals called absorption bands. For a practical consideration of gas radiation, different numerical simulation approaches exist. In general, these approaches are either gray gas models or non-gray gas models. The simple gray gas model (SGG) considers the effective absorption coefficient as the main parameter controlling the radiative properties of a gas mixture and assumes that radiant absorption and emission by gas molecules to be independent of the frequency of the radiation [4]. One of the more advanced non-gray models is the exponential wide band model (EWBM), which is based on experimental methods to analyze absorption of electromagnetic waves in gases [4]. The EWBM provides a set of semi-empirical expressions to predict the total band absorption. The EWBM can be used to predict radiative properties dependent on temperature, total pressure range, volumetric fraction and path length [5]. The EWBM was developed by Edwards and Menard [6], as well as Edwards and Balakrishnan [7]. The following relation is used to calculate the spectral absorptivity $\alpha_{\eta,i,j}$

$$\alpha_{\eta,i,j} = 1 - exp\left(\frac{-(S/d)_{i,j}\varrho_i L}{\sqrt{1+\frac{(S/d)_{i,j}\varrho_i L}{\beta_{i,j}P_{e,i}}}}\right) \tag{1}$$

where i refers to the absorbing species; j refers to the band number; $(S/d)_{i,j}$ is the mean line intensity to line spacing ratio; ϱ_i is the density of the absorber; L is the path length; $\beta_{i,j}$ the mean line width to spacing ratio at 1 atm total pressure; $P_{e,i}$ is the dimensionless equivalent broadening pressure for each species. The parameters used in the EWBM model are tabulated for relevant species and are found in literature, e.g. [8, 9].

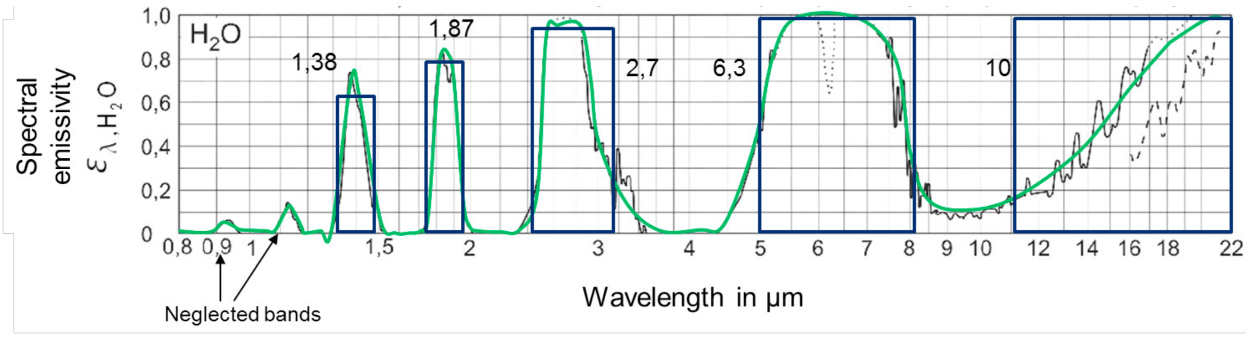

Fig. 1 Spectral emissivity dependent on wavelength of water.

Fig. 1 shows the spectral emissivity of water vapor for 100 cm path length, at ambient temperature and pressure. The black curve shows the experimental data obtained from Eckert [10]. The green curve represents the results of the EWBM model, and the rectangular fields are the discrete emissivity bands. The benefit of the EWBM model in comparison to gray gas radiation models is its higher accuracy and the consideration of absorption bands. However, such models correlate with experimental data with an average error of approximately 20 % [8]. Furthermore, the models require high computational effort, since all data have to be integrated over wave-length.

As we will show in this paper, using the SGG model to predict radiative heat transfer through atmospheres typical for combustion may lead to significant overestimation of heat transfer rates.