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Modeling Radiation Heat Transfer of Natural Gas–Hydrogen Blends in a Lab-Scale Oxyfuel Furnace

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Reducing the environmental impact of hard-to-abate industries, such as metal and glass production, has driven efforts to enhance high-temperature processes. Oxyfuel combustion is widely adopted to improve efficiency and reduce both fuel consumption and CO_2 emissions, with staged oxyfuel burners favored for their ability to control flame temperature, pollutant formation, and heat transfer. However, full decarbonization may require the replacement of natural gas with hydrogen. This work numerically investigates the impact of gas radiation modeling in a 320-kW lab-scale furnace equipped with a staged oxyfuel burner, operating under various natural gas–hydrogen fuel blends, from pure natural gas to pure hydrogen. Steady Reynolds-Averaged Navier–Stokes (RANS) simulations are carried out using the Eddy Dissipation Concept (EDC) combustion model coupled with a skeletal reaction mechanism. The radiative transport equation (RTE) is solved using both the first-order spherical harmonics (P1) and discrete ordinates (DO) methods. Gas radiation is modeled using a weighted sum of gray gases (WSGG) model, derived from full-spectrum k-distributions and specifically calibrated for hydrocarbon–hydrogen oxyfuel combustion. The calibrated WSGG model accurately captures the spectral characteristics of CO_2 and H_2O in the natural gas–hydrogen mixtures. Within the DO–WSGG framework, two spectral treatments are evaluated: (i) the traditional gray-gas approach, which solves a single RTE using an effective absorption coefficient, and (ii) a multi-band formulation, in which separate RTEs are solved for each gray gas. Additionally, the influence of soot—typically present in natural gas staged oxyfuel combustion—on radiative heat transfer is assessed.