602d Improved Estimates of High Temperature Fiber Bed Effective Emissivities from Variational Calculations

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The effective bed emissivity plays a significant role in the heat transfer processes for high temperature systems. The significance of enhancing the value of the effective emissivity can be illustrated by a number of important fiber bed examples. The space shuttle surfaces are protected by the radiative emission of the searing heat generated by the reentry air friction. The shuttle high temperature reusable insulation tiles which cover the high temperature areas (650-1260°C) are designed to enhance their effective emissivity coefficient. Another case of fiber bed boundary radiation heat transfer occurs with the carbon fiber-carbon matrix brakes used in commercial and military jet aircrafts. The brake temperature during a rejected takeoff can exceed 2000°C, and increasing the effective emissivity ε_{eff} of both the fibrous frictional contact and external surfaces will influence brake performance, wear and safety. Potential uses of carbon fiber beds as very high temperature gas-solid heat exchangers for furnaces or fusion facing heat transfer components for hydrogen fusion electric power plants will depend on the bed ability to absorb radiant energy, i.e. the value of ε_{eff}. Fiber bed emissivity values are important for energy transfer processes during the high temperature manufacturing of ceramic/ceramic fiber and carbon/carbon fiber composites by chemical vapor deposition reactions.

A variational principle was applied to obtain rigorous upper bounds for the effective bed emissivity ε_{eff} of a semi-infinite fiber bed made up of long, parallel, overlapping cylinders for two possible bed edges—fibers perpendicular and fibers parallel to the bed edge. Calculations of bed emissivity variational results for both cases provided significant improvement over first order scattering upper bounds given in a previous paper. For high void fraction $\Phi \to 1$ and fiber surface emissivity values of ε_s=0.5, 0.3 and 0.1, respective bed emissivity upper bound improvements of 46.78%, 12.69% and 9.39% were obtained for the former case, and 48.55%, 11.74% and 7.59% were generated for the latter bed edge structure.

Along with the first order scattering lower bounds on ε_{eff}, improved estimates of bed emissivities were calculated for high temperature nonmetallic fiber beds with $\varepsilon_s \geq 0.55$. Bed emissivity enhancement factors ($\varepsilon_{eff}/\varepsilon_s$) of 1.27 for fibers parallel to the semi-infinite bed edge and 1.42 for fibers perpendicular to the bed edge were obtained for high fiber bed porosity Φ=0.9 and ε_s=0.55. Results were compared with an experimental correlation and Monte Carlo simulations, and good agreements were obtained.