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Simulation of the Spectral Conducto-Radiative Exchanges within Semi-Transparent Heterogeneous Media

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Extended Abstract

For several decades now, numerous studies have been dedicated to porous refractory materials and their effectiveness in high temperature processes does not need to be proved anymore. Yet, an accurate identification of the thermal properties and the prediction of the thermal transfers in these media remains a challenge in some cases. A concrete example is the difficulty to predict the heat exchanges within semi-transparent materials. Indeed, in such media, the behavior towards thermal radiation varies with both the frequency of the radiation and the temperature. In other terms, the material can behave as opaque in a specific spectral range (conduction will then prevail) and can be totally transparent in another part of the spectrum where thermal radiation will be predominant. Therefore, a classic conducto-radiative simulation on a semi-transparent medium, where the radiative properties of the material are assumed constant with frequency and temperature, will fail to reproduce the real thermal behavior of the medium.

To illustrate this point, the behavior under a heat flux of a fibrous material impregnated with silica aerogel was analysed. The experiment carried out made it possible to bring the front face of a 10 mm thick plate of this material to 3 temperature levels (300, 500, and 800°C) in 200 s, maintain these levels until 600 s and measure the evolution of the temperature of its rear face over time. On the three thermograms, a sudden increase in temperature was observed. This was due to the silica aerogel becoming transparent to thermal radiation at a given spectral range and specific temperature [1].

The French Alternative Energies and Atomic Energy Commission (CEA) develops a code to evaluate the conducto-radiative exchanges within 3D voxelized microstructures [2][3]. In this program, each voxel represents a unique phase (fluid or solid) and is considered homogeneous and non-scattering. The heat equation is computed in each voxel with a finite difference scheme where the radiative contribution is input as a power source. This latter is calculated by solving the Radiative Transfer Equation (RTE) within each voxel.

During this work, this code was upgraded to take into account the spectral dependency in the calculation to correctly predict the evolution of temperature with time of a semi-transparent medium such as the one presented previously.

To do so, the spectral domain is split into a number of N relevant bands and the RTE is solved with the corresponding radiative properties for each band. The resulting radiances of each of these bands are eventually summed up in order to get a total radiative heat flux as in a classic grey (non-spectral) computation, which is then input in the heat equation.

Thanks to a methodology developed in a previous work (in process of publication), the spectral radiative properties of the material presented above were identified to compute both grey and spectral conducto-radiative exchanges in transient regime with the CEA code. The spectral simulation was in good agreement with the experiment while the grey one failed to reproduce the sudden increase in temperature observed experimentally. These results confirmed the relevance of performing spectral calculations instead of grey ones to characterize semi-transparent materials.

References

[1] F. Enguehard, "Multi-scale modeling of radiation heat transfer through nanoporous superinsulating materials", *International Journal of Thermophysics*, vol. 28, n°5, 2007.
[2] M. Niezgoda, D. Rochais, F. Enguehard, B. Rousseau, P. Echegut, "Modeling heat transfer within porous multiconstituent materials", *J. Phys. Conf. 369.,* 2012.
[3] C. Heisel, C. Caliot, T. Chartier, S. Chupin, P. David, D. Rochais, "Digital design and 3D printing of innovative SiC architectures for high temperature volumetric solar receivers", *Solar Energy Materials and Solar Cells*, vol. 232, 2021