A finite element solver for modeling coupled heat transfers in architectured porous media up to very high temperature

Salih Ouchtout*[1], Laurent Cangemi[1], Yann Favennec[2], and Benoît Rousseau[2]

[1]IFPEN Rueil-Malmaison – IFPEN, IFP Energies nouvelles, 1 et 4 avenue de Bois-Préau, 92852 Rueil-Malmaison, France. – France

[2]LTeN Université de Nantes – Laboratoire de Thermique et Energie de Nantes (LTeN UMR Université de Nantes—CNRS 6607) – France

Résumé

Concentrated solar power systems constitute today a promising route to produce industrial heat at T = 800-1500 K for strategic high temperature applications (cement production, steam cracking, hydrogen production). The same free-carbon heat can be used for producing electricity in 100 MW power plants according to the solar-to-heat conversion technologies. During the last few years, increasing attention has been given to employ architectured porous ceramics with prescribed textural features for designing volumetric solar receivers likely to deliver hot air at T =1000 K. These receivers are installed on the top part of a high-temperature solar tower. However improvements must still be made to reach conversion efficiencies higher than 85 % at T = 1000 K for considering massive industrial developments. To reach such efficiencies, it is fundamental to understand how heat is distributed in the volume of the porous receiver. In this work, we present and study a nonlinear coupled integro-PDEs model combining both the phenomena of convection, conduction and radiation in a porous medium, representing the volumetric solar receiver. The coupled model is governed by 4 subproblems. The first is an integro-differential equation representing the phenomenon of radiation (absorption and scattering processes). The second and the third are nonlinear partial differential equations representing the heat conduction equation of the solid and the fluid phase respectively. The fourth one is composed of two nonlinear equations (momentum equation and continuity equation), describing the fluid flow, and modeled by the Darcy-Brinkmann-Forchheimer equations, representing the convection phenomenon. We carry out the analysis and the numerical approximation of the model within a variational framework and we perform the full discretization of the problem based on the discrete ordinate method for the angular discretization and the finite element method (standard FE, vectorial FE, Mixed FE and SUPG-FE) for the spatial discretization. All non-linearities are handled using a fixed-point method coupled with a Newton–Raphson linearization method. We consider a three-dimensional geometry (cube or cylinder) in order to represent the volumetric solar receiver. We start the numerical results by investigating the coupling problem of all physics as well as the troublesome obstacle of several nonlinearities. To do that, we present and compare, in terms of convergence and computational cost, different possible strategies for solving such a proposed coupled problem. In addition, the effectiveness of our solver's numerical strategy is based on a parallel distribution, developed using domain decomposition. Then, we proceed to study the coupled problem of convective, conductive and

*Intervenant

radiative heat transfers within the volumetric solar receiver, and we perform several numerical simulations of all the variables involved. The results are discussed regarding the effect of different parameters (initial velocity, porosity, mean cell size diameter, etc.) on the thermal efficiency of the volumetric solar receiver. Moreover, it will allow us to better understand the role of each mode of heat transfer on the volume distribution of all the thermal quantities (temperature, flux) involved. Our FEM-solver is also important for designing afterwards porous architectured ceramics using a topology optimization route.