ME – PhD Thesis Defense

One-domain simulation of fluid flow and heat transfer in the conjugate porous-clear media

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ABSTRACT

In this thesis, based on generalized porous flow model, we present a one-domain framework for the simulation of incompressible flow in superposed clear and porous media. The continuous change in the characteristics of the porous medium is naturally taken into account by the model. In presence of any strong discontinuities in the domain, the sudden changes are approximated as a continuous but rapid variations over a thin layer across the regions of contrast. The governing equations are solved by a consistent second-order projection scheme on finite volume octree cells. Benchmark problems with flow parallel and perpendicular to the homogeneous porous layer are considered to test the accuracy of the proposed numerical model especially with regard to the artificial transition region. Although the incorporation of the transition layer introduces error into the system, it reduces non-linearity in the field variables and, therefore, decreases the demand of higher grid density near the interface in one-domain approach. Furthermore, to illustrate the ability of our solver to handle flows with viscous as well as inertial effects around a planar or circular interface geometry, we simulate a series of physical problems with varying complexity in flow and characteristics of porous medium.

Subsequently, fluid flow in partially porous square cavity with top wall moving in its own plane is analyzed for different Darcy number, porous fraction, and orientations of porous-clear interface at fixed Reynolds number Re $= 10^3$ and porosity ($\varphi = 0.7$). Darcy number (Da) and porous fraction (η) are varied in the range 10^{-5} to 10^{-1} and 0 to 1, respectively. For a given porous fraction, three arrangements of porous material resulting in interface oriented at an angle (α) of 0^0, 45^0 and -45^0 relative to the moving wall are considered. The +ve and -ve signs of α indicate that the interface is inclined toward and away from the direction of wall's movement. Our numerical results suggest that variation in permeability of the porous medium has significant influence on the flow features in high Darcy number regime. Whereas, flow behavior is mainly governed by the size as well as the geometry of the clear section in low Darcy number regime. Also, for a given permeablity and porous fraction, arrangement of porous material with interface angle 45^0 and -45^0 offer the least and highest resistance to the flow, respectively. In this study, maximum value of stream function in the cavity (Ψmax) and minimum value of vorticity along the moving wall (ωmin) are the quantities of interest. Finally, numerical simulation of buoyancy induced incompressible flow and heat transfer in a side heated square cavity with porous layer placed on inner walls is presented. Here, porosity is assumed to increase linearly from εw at the wall to 1.0 at the edge of the porous layer. Also, permeability is taken as a non-linear function of porosity, given by Kozeny-Carman relation. The key parameters in the simulation are Rayleigh number Ra $= 10^4 - 10^7$, solid-to-fluid thermal conductivity ratio (Rk $= 0.1 - 100$), dimensionless pore diameter (Dp $= 0.005 - 0.05$), wall porosity (εw $= 0.2 - 0.9$), dimensionless porous layer thickness (W $= 0.1 - 0.5$), and porous-to-fluid heat capacity ratio (Rc $= 0.1 - 10$). Steady-state solutions are analyzed in the form of contours as well as profiles of field variables and local as well as average Nusselt number along the hot wall.

ABOUT THE SPEAKER

After completing his Bachelor's and Master's degrees at I.I.T. Kharagpur, Abhijit began his career as a software developer, working with ESI Group, Parametric Technology Corp. (PTC), and Dassault Systèmes. With over eight years of industry experience, he decided to pursue a Ph.D. in Mechanical Engineering at IISc Bangalore. During his doctoral studies, he developed a numerical framework for simulating transport phenomena in conjugate porous-clear systems. Using this framework, he investigated shear and buoyancy-driven flows in cavities partially filled with homogeneous and heterogeneous porous material.