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Keynote Lecture III

Dynamics of Shear Layers at Porous Medium - Pure Fluid Interfaces with and without Heat Transfer

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Abstract - In this talk, we discuss recent progress on the dynamics of shear flows in hybrid domains, i.e. domains that include a macroscopic interface between a porous medium and a pure fluid. Such flows are often encountered in nature as well as in technological applications. Examples of relevant natural phenomena are: wind through forest canopies and through urban areas, water flow through coral reefs, solidification of multi-component melts and others. Also from the technological point of view, such flows can be found in fuel cells, air filtration systems, carbon nano-tube forests, etc.

In the first part of the talk, we focus on the modelling aspects of the flows of interest, focusing primarily on the co-called “single-domain” approach. According to this approach, the porosity is introduced as a field variable and a single set of governing equations is derived which is valid both inside and outside the porous medium. The advantage of this method is that it does not require the introduction of matching conditions at the macroscopic interface. Then, since a porous medium constitutes a granular material with zero velocity and prescribed porosity, we employ a continuum theory for fluid-saturated granular materials, developed by the author, for the derivation of a flow model for hybrid domains. The resulting set of equations constitutes a variation of what is collectively referred to as the unsteady Darcy-Brinkman equation. Numerical methodologies for the solution of such equations are also presented and elaborated.

In the second part, we discuss some recent analytical and numerical results for isothermal shear flows in hybrid domains. More specifically, we present the results of a linear-stability analysis for inviscid shear layers in hybrid domains. As it turns out, such layers are unstable at all frequencies and porosities. At high wave-numbers, the growth rates of instabilities decrease with porosity. Nonetheless, the maximum values of the growth rates occur at low wave-numbers and increase with porosity, as expected. Subsequently, we discuss results from numerical simulations of temporally evolving shear layers in both two and three dimensions. According to these simulations, the onset of the Kelvin-Helmholtz instability leads to the formation of vortices that extend to both sides of the material interface, thus producing significant recirculation inside the porous medium. These vortices eventually merge, leading to significant growth of the shear layer and, in three-dimensional flows, transition to turbulence.

The third part of this talk is concerned with shear flows in hybrid domains with heat transfer. First we discuss modelling and computational aspects for the flows of interest; Emphasis is given on the issue of thermal non-equilibrium between the two phases and the relevance of the poro-elastic properties of the solid matrix. Next, we present results from direct simulations for both Rayleigh-Bénard and forced convection. As regards Rayleigh-Bénard convection, attention is paid to the sensitivity of the flow properties due to the presence of the porous medium and the alteration of patterns induced by the associated Rayleigh-Bénard instability. Finally, as regards forced convection, emphasis is placed on the effects of heat transfer to the shear-layer characteristics, such as self-similarity, vortex pairing, etc.