THE EFFECTS OF POROUS BLOCK ON TRANSIENT NATURAL CONVECTION IN VERTICAL ANNULAR DOMAIN

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A numerical analysis is performed to investigate the effect of attaching a porous obstacle on the inner boundary of a vertical annular domain. The side walls of the cylinder are maintained at constant temperatures, while the horizontal walls are adiabatic and impermeable. The analysis is performed for a fixed Grashof number 10^7, the obstacle has a fixed size and different permeabilities in order to cover large domain between the two asymptotic limits: fluid and solid cases. The problem is considered as two-dimensional (angular symmetry) and the density variation is taken into account by the Boussinesq approximation. The governing equations of the problem, expressed with the primitive variables P-V, are solved using a finite volume approach by considering the transient resolution (DNS). The temporal variation of the heat transfer (Nusselt number) is analysed for different values of Darcy number in the porous obstacle. The problem modelisation is assumed by a Darcy-Brinkman formulation allowing: the solid model (solid obstacle), the Darcy model (low permeability), the Brinkman model (moderate permeability) and pure viscous fluid (very high permeability: without obstacle). We illustrate the necessary conditions in order to improve the transfer in such a configuration.

INTRODUCTION

Natural convection heat transfer is of great interest in industrial applications, like the cooling of the electronic components, nuclear technologies, heat exchangers, storage energy tank and other fields. This work deals with the effects of adding a porous block on the dynamic heat transfer especially in a cylindrical configuration where non-symmetrical solutions are obtained. The added block is located in the boundary layer of the inner vertical cylinder as shown in figure 1. The considered domain sizes are the vertical dimension H, inner radius r'_i and outer radius r'_0 (fig.1). The inner and outer vertical surfaces are maintained at different uniform hot (T_h) and cold (T_c) temperatures respectively. The top and bottom boundaries of the domain are supposed thermally well insulated and impermeable.

The aspect ratio of the cavity is equal to one, the domain curvature is $R = \frac{r'_0 - r'_i}{r'_i} = 2$ and the fluid is air (Pr =0.7). The dimensionless obstacle height and width are given respectively by h and e and keep fixed in this study at a value of 0.1. The obstacle is located at mid-height of the inner cylinder. The conductivity of the obstacle (insulator) is consideral relatively equal to the air conductivity value. We suppose that the radiative transfer and the viscous dissipation are negligible. The density variation is taken into account by the Boussinesq approximation. We use a second order time and space scheme discritisation in the resolution of the governing equations.

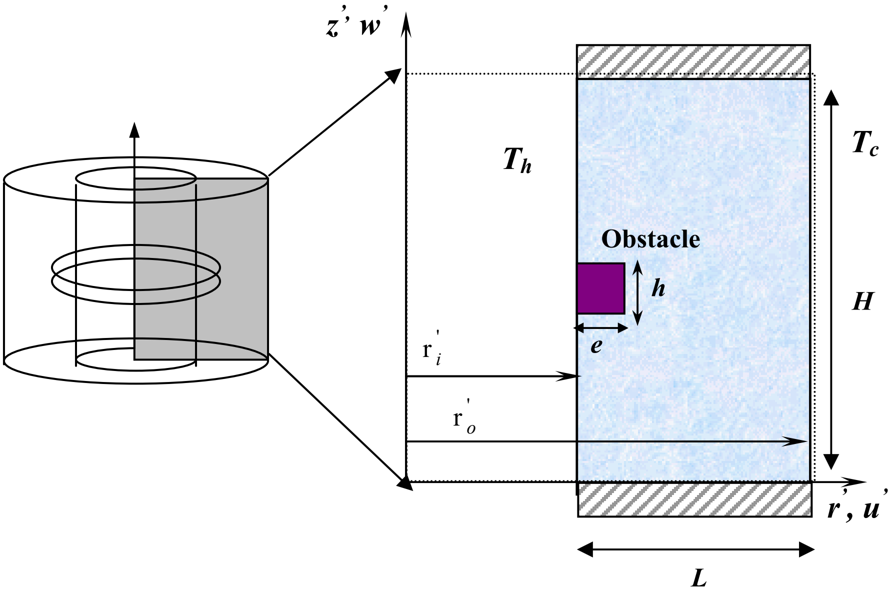


Fig. 1. Schematic view of the physical configuration

RESULTS AND DISCUSSION

Figure 2 represents temporal variation of the normalised average Nusselt for various Darcy numbers. We note that the time necessary to reach steady state increases by decreasing the Darcy
number.

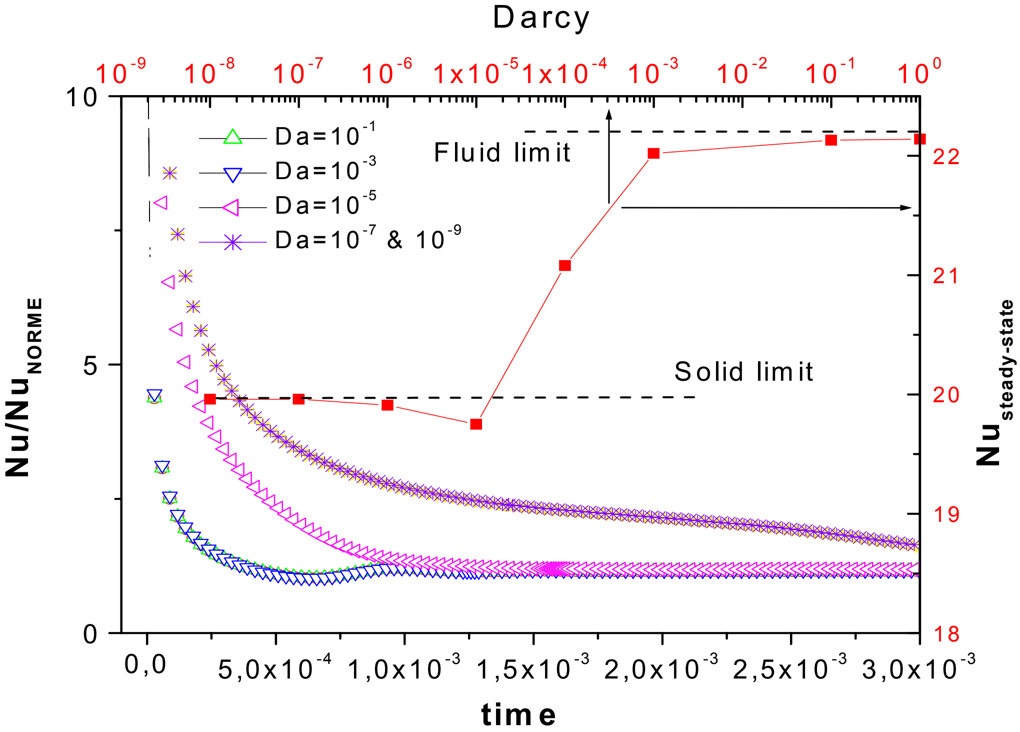


Figure 2: Darcy effect on heat transfer (Nu) in transient and steady states

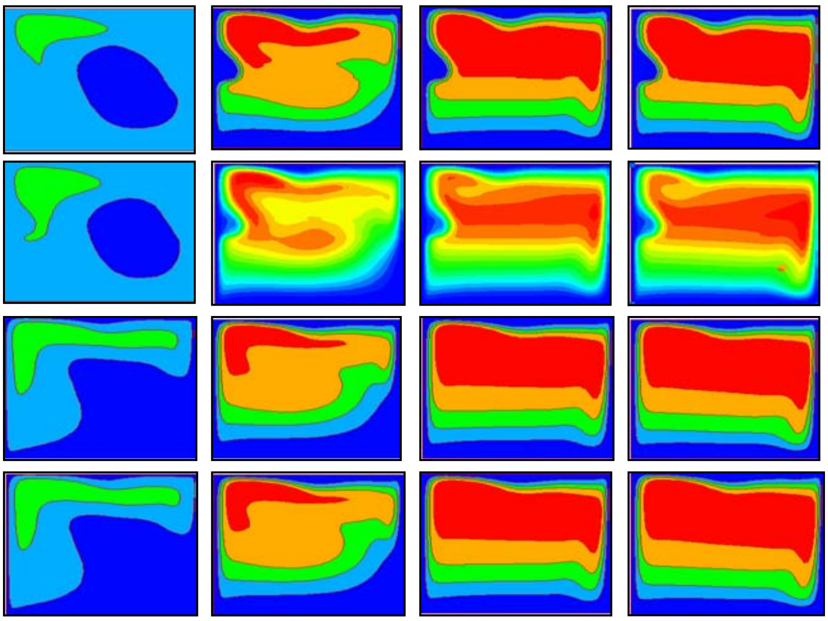
By decreasing the Darcy number, the flow penetration is weak in the porous layer, which is behaves as a solid wall. The flow strength is lower and the system needs to mix the global contained fluid to reach steady state longer time. The second reason that is in same time origin and consequence of the flow (via the strong coupling) is the decrease in the heat transfer with the Darcy number decreases. We found also that the curvature and the block reduce the overshooting phenomena.

The variation of average Nusselt in steady state is also represented on Figure 2. The more we decrease the Darcy value the more the heat transfer decreases. The heat transfer change is from high transfer: fluid limit (without block) to low transfer: solid block limit (very low Da). We underline a specifically and surprising result for Darcy of 10^{-5} where the heat exhibit a minimum value. This can be explain as:

- For a low permeability, the flow is negligible in the porous layer. As a result the heat in the porous layer is mainly conductive. The global transfer is lower due to the added thermal resistance.
- For Da = 10^{-5}, the increased reduction of heat transfer is due to two distinguishing obtained flows: one threw the block and another around it. The flow threw the block results in a local fluid temperature increase. The hot fluid at the exit from the block acts as an insulator by decreasing the thermal gradient in the vicinity (after the block) of the hot vertical surface. This remark is obvious from the local heat transfer (not represented here due to the lack of place).
- For high permeabilities, we have one main flow with a classical boundary layer with a significant heat transfer and tend to a value identical to those of a totally fluid cavity.

The Darcy number effect on both the time evolution and steady state heat transfer values can be illustrated by plotting the streamlines at different dimensionless time (0.005, 0.01, 0.003 and 0.07) for some given Darcy numbers. The effect of the block permeability on the flow and the resulting thermal field is obvious.

We found also another interesting strong effect on the flow dynamic and the resulting heat transfer by changing the domain curvature.



Da=10^{-9}

Da=10^{-5}

Da=10^{-3}

Da=10^{0}

t=0.005 t=0.01 t=0.03 t=0.07

Figure 3: Time evolution of stream function for different Darcy