COMBINED MIXED CONVECTION AND RADIATION IN A CHANNEL DISCRETELY HEATED FROM BELOW

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INTRODUCTION

The study of the heat transfer by mixed convection in tilted channels has received a growing interest during the last decades. This interest is dictated by the role played by such configurations in the field of the habitat, the design of the solar heat collectors and more recently the cooling of the electronic cards (because of the tendency to the miniaturisation of the components). An exhaustive review of the literature shows that the case of mixed convection in a ventilated system was examined by several authors[1-3]. However, the effect of radiation was often neglected in the majority of the available studies in spite of its significant contribution to the heat transfer in such systems. Its effect was rather taken into account in rectangular closed[4-5] or opened[6-7] geometries in the case of natural convection. In comparison with these studies, the case of opened systems with radiant walls in mixed convection hardly starts to arouse interest [8].

The objective of this work consists in studying the coupling between mixed convection and radiation in a rectangular channel, discretely heated from below. The effect of the emissivity of the walls, ε, and the angle of inclination of the channel, θ, on the flow fields, the temperature distribution and the heat transfer rate will be examined.

MATHEMATICAL FORMULATION AND RESOLUTION METHOD

The system under consideration is shown in Fig. 1. It consists of a channel of finite length, with an aspect ratio A = 10, inclined with respect to the horizontal and discretely heated from below. The top wall of the channel is maintained at a cold uniform temperature. The system is submitted to an imposed flow of ambient air, parallel to the plates. The flow is considered two-dimensional and laminar. The Navier-Stokes governing equations, written in vorticity-stream function formulation (Ω-Ψ), were solved by using the Alternate Direction Implicite method (ADI).

The hydrodynamical boundary conditions are characterized by the impermeability of the rigid boundary and the no-slip of the fluid particles on these boundaries: u = v = 0. At the entrance of the channel, T = v = Ω = 0, u = 1 and Ψ = y. On the heated elements and the cold wall, the non-dimensional temperatures are fixed respectively at T = 1 and T = 0. The boundary conditions at the exit of the channel are obtained by mean of an extrapolation technique similar to that used in references[1-3]. Since the working fluid (air) is transparent to the radiation, the contribution of the latter appears only in the thermal boundary conditions. Thus, the heat received by radiation on the adiabatic portions is restored to the fluid by conduction according to the relation:

$$-\frac{\partial T}{\partial y} + N_r Q_r = 0 \qquad (1)$$

where N_r and Q_r are respectively the conduction-radiation parameter and the non-dimensional radiative heat flux calculated by using the radiosity-irradiation method combined with some useful approximations (gray surfaces, isotropic emissions).

HEAT TRANSFER

The average Nusselt numbers characterizing the contributions of mixed convection and radiation through the heated wall are respectively defined as:

$$Nu_b(conv) = -\frac{1}{B}\int_0^B \left.\frac{\partial T}{\partial y}\right|_{y=0} dx \qquad Nu_b(rad) = \frac{1}{B}\int_0^B \left. N_r Q_r \right|_{y=0} dx \tag{2}$$

The total Nusselt number is evaluated as being the sum of the convective and radiative Nusselt numbers.

RESULTS AND DISCUSSION

Variations, with the inclination angle θ, of the convective Nusselt number Nu_b(conv), evaluated on the heated wall are presented in Fig. 2 for Ra = 10^5 and Re = 50. It can be seen that Nu_b(conv) increases with θ for the different values of ε. This is due to the increase of the natural convection effect by increasing θ. Also, for ε = 1, a multiplicity of solutions was obtained. The corresponding flow structures consist of two solutions : reversal flow (**S_1**) and monocellular with a small reversal flow at the exit of the channel (**S_2**). The **S_2** solution is found to be more favourable to the heat transfer than the **S_1** one in the range 10 ≤ θ ≤ 60°. Above this range, the two solutions contribute equally to the convective heat transfer. This multiplicity of solutions was obtained for lower values of Re (results not presented) for all the considered values of ε. It disappears here for ε = 0 and 0.5 as a consequence of the increase Re, which weakens the natural convection effect. The effect of radiation on the overall heat transfer was also examined (results not presented). It was found that the total heat transfer across the heated wall increases quickly with ε.

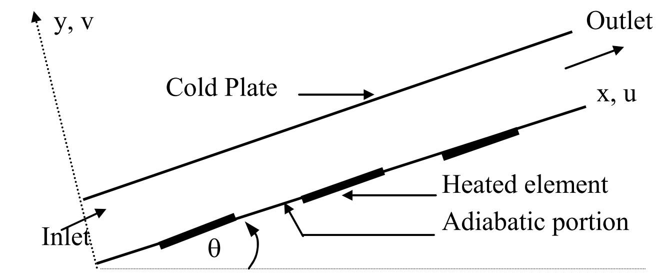


Fig. 1 : Studied configuration.

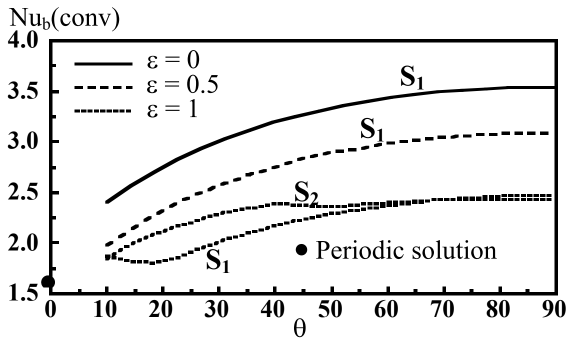
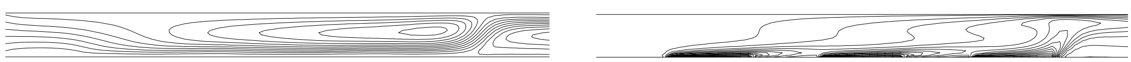


Fig. 2 : Variation of Nu_b(conv), with θ, for Ra = 10^5, Re = 50 and various values of ε.

Streamlines and isotherms illustrating the multiplicity of solutions are presented in Figs. 3a-3b for θ = 30°, ε = 1, Ra = 10^5 and Re = 50. In Fig. 3a, we note the presence of a large closed cell within the channel floating over the open lines of the forced flow, with the appearance of a small return flow developing just in the lower part of the exit (**S_2** solution). The corresponding isotherms display a distortion within the channel testifying of a big fluid circulation at the level of the central closed cell. The presence of this closed cell is found to enhance the convection across the cold wall (results not presented). In Fig. 3b, we note the development of a return flow occupying a great part of the space allowed inside the channel. This flow structure (**S_1** solution) is found to favour the convective heat transfer at the exit of the channel and reduces the convection effect at the level of the cold wall.



a)

b)

Fig. 3 : Streamlines and isotherms obtained for Ra = 10^5, Re = 50, ε = 1 and θ = 30° (two multiple solutions): **a)** $\mathbf{S_2}$ solution (Ψ_{min} = -0.6, Ψ_{max} = 1.8) and **b)** $\mathbf{S_1}$ solution (Ψ_{min} = 0, Ψ_{max} = 2.1).

For values of θ ≥ 10°, it can be noted that all the solutions were found to be steady. However, for θ = 0° and ε = 1, the fluid flow becomes unsteady and periodic oscillations were observed. This behaviour is well illustrated by presenting the time history of Ψ_{max}, Ψ_{min} and Nu_b(tot) in Figs. 4a-4c after reaching a stationary state. The periodic oscillations are characterized by relatively significant amplitudes. Such periodic solutions were obtained in a previous work dealing with combined mixed convection and radiation in ventilated cavities[8]. In order to make sure that the boundary conditions at the exit are not causing these instabilities, other conditions used in the literature[6-7] were tested. The nature of the oscillations and their amplitudes did not undergo notable changes.

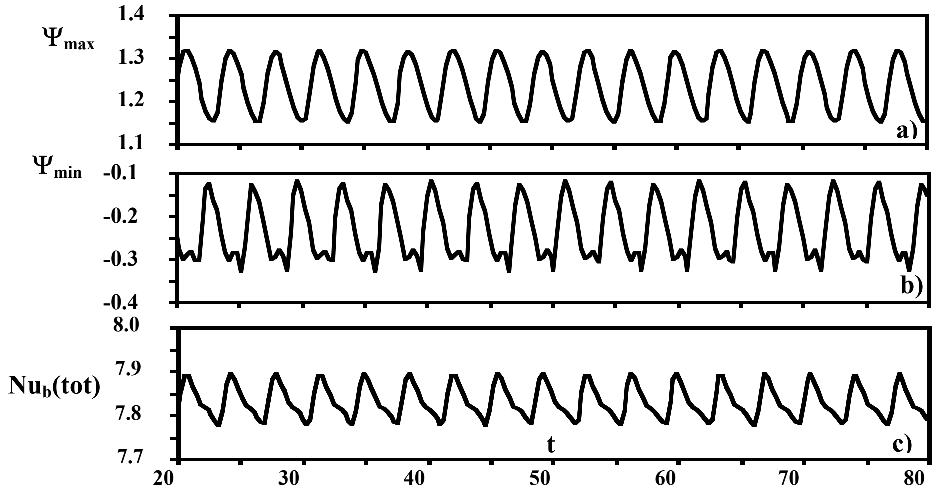


Fig. 4 : Periodic oscillations of Ψ_{max}, Ψ_{min} and Nu_b(tot) for Ra = 10^5, Re = 50, ε = 1 and θ = 0°.

CONCLUSION

The effect of thermal radiation on the fluid flow, the temperature distribution and the heat rate across a channel discretely heated from below was studied numerically. Results of the study shows that the effect of radiation acts in decreasing/increasing notably the convective/overall heat transfer. Also, a multiplicity of solutions and transient periodic oscillations were obtained for this problem.

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