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Mixed convection flow investigation in a rectangular horizontal tube stenosis via liquid crystal thermography and planar PIV

Ch. Stamatopoulos [a], D.S. Mathioulakis [a,*], A. Katsamouris [b]

[a] School of Mechanical Engineering, Fluids Section, National Technical University of Athens, 9 Heroon Polytechniou Ave., Zografos 15710, Athens, Greece
[b] Division of Vascular Surgery, Medical School, University of Crete, P.O. Box 2208, 71003 Heraklion, Crete, Greece

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ABSTRACT

The temperature and velocity field in a horizontal convergent–divergent rectangular channel heated from below is studied experimentally for a Reynolds range 8–120, Grashof numbers from 0.44×10^5 to 2.56×10^5 and Richardson numbers from 3 to 4000, using water as working fluid. The duct aspect ratio (width/height) varies from 1 at its inlet to 2.28 at the stenosis neck, and both the upper and bottom walls are tilted with an angle of ±15.7° with respect to the horizontal. The temperature of the bottom wall is kept constant above that of the issuing fluid. The temperature field is recorded by liquid crystals in the vertical mid plane whereas the velocity field is measured in this plane as well as in four cross sections of the divergent passage by planar PIV, revealing the characteristics of the secondary velocity field. For all the examined cases the flow in the convergent passage is free of thermal plumes, and the thermal boundary layer is thin. In contrast, the divergent passage is characterized by a thermal plume which is shifted upstream with increasing Gr or reducing Re. Both transversal and longitudinal rolls emerge in this diffuser the strength of which depend on Re and Gr influencing the streamwise distribution of Nusselt which for low Re presents a minimum.

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1. Introduction

The flow structure over flat plates and channels heated from below presents interesting features mainly associated with thermal instabilities caused by buoyant forces. Various engineering applications are related to the above cases, like flow in heat exchangers, cooling of electronic devices, solar heating, manufacturing of thin films over silicon wafers (chemical vapor deposition) etc.

Depending on the orientation of the wetted surfaces with respect to the horizontal as well as the relationship between Grashof (Gr) and Reynolds (Re) number, flow structures having the shape of longitudinal and transversal vortices appear, and under certain conditions the flow field becomes unstable and chaotic. Due to the buoyant plumes emanating from the heated surfaces, secondary flow becomes significant, affecting the local Nusselt number (Nu) which thus varies strongly in space.

A review paper by Lin [1] describes various interesting configurations of vortex patterns induced by buoyancy in a channel for small Re. The transition from longitudinal to transversal vortices and vice versa was examined experimentally by Chiu et al. [2], in both a horizontal and a convergent rectangular channel heated from below. They showed that it is the relative significance of the buoyant forces compared to the inertial which is related to the appearance of one type of vortices or the other. In a computational work by Khanafer and Lightstone [3] the influence of the inclination angle of a heated plate upon the suppression of the secondary flow was studied for low Re (smaller than 50) and Gr numbers up to 4.3×10^6. Employing liquid crystals, Jeschke et al. [4] measured the wall temperature (T_w) and local Nusselt number distribution over a tilted flat plate, uniformly heated, under natural convection conditions. The spanwise variation of T_w and Nu was associated with upwash (hot water) and downwash (cold water) regions the size of which changed streamwise. The evolution of streamwise vortices was examined by Maughan and Incropera [5] over a heated horizontal water channel using flow visualization. Under laminar pure forced convection (Re < 1000), they identified four regimes, namely laminar forced convection (at the plate leading edge), laminar mixed convection, transition to turbulence and finally turbulence. The role of the longitudinal vortices in turbulent transition of natural convection flow over a tilted flat plate with an angle between zero and 90 degrees from the horizontal was examined by Kimura et al. [6]. They showed that for inclination angles below 72° these vortices play the role of a triggering mechanism to turbulence. The same group of researchers in a previous work [7], conducting experiments over a heated flat plate, proved that a thermal plume appears for inclination angles smaller than 15°, so that both ascending and descending flows coexisted

* Corresponding author. Tel.: +30 210 772 1020; fax: +30 210 772 1057.
E-mail address: mathew@fluid.mech.ntua.gr (D.S. Mathioulakis).

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