1D Channel Flow Patterns in Shallow Enclosure Horizontal Convection

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Abstract

Horizontal convection is a distinctive class of natural convection, where non-uniform heating and cooling occurs along just one horizontal boundary of the enclosure. Studies ofhorizontal convection have been inspired by the transport of warm fluids in the oceanic circulation [1] and engineering processes, like glass melting in furnaces [2]. Previous experimental [3, 4] and numerical [2, 5] studies informed the heat transfer scalings and flow dynamics considering a change of Rayleigh numbers (Ra) for a fixed or a narrow range of aspect ratios (ratio of height to length, A). The lowest reported aspect ratio ($A = 0.16$) is at least two orders of magnitude larger relevant to the oceans. This study aims to emphasise shallow enclosure horizontal convection flow dynamics and heat transfer scalings by varying aspect ratios and explores the connection with the 1D-channel flow. A water-filled rectangular enclosure of length L and height H is studied. The flow with buoyancy modelled using a Boussinesq approximation is driven by imposing a linear temperature profile on the bottom boundary of the enclosure, and insulating temperature conditions on the remaining boundaries. The 2D incompressible Navier–Stokes equations augmented by a buoyancy term in the momentum equation and a scalar advection-diffusion transport equation for temperature were solved by a high-order in-house solver, which employs a spectral-element method for spatial discretisation and a 3rd-order time integration scheme based on backwards-differencing.

Numerical simulations are conducted for a wide range of aspect ratios ($0.001 \leq A \leq 0.16$) and Rayleigh numbers ($10 \leq Ra \leq 10^{17}$) maintaining a fixed Prandtl number ($Pr = 6.14$), representative of water. The logarithmic values of the calculated Nusselt number (Nu) and $RRRR$ are presented in figure 1(a), which depicts that increasing $RRRR$ governs the flow from a diffusion-dominated regime ($Nu \sim A$) via a transition regime ($Ra \sim A^{-4}$) towards a steady-state convection-dominated regime ($Nu \sim Ra^{1/4}$). Figure 1(a) is rescaled in 1(b) based on the obtained scalings, which plots log ($Nu\ /A$) against log(RaA^4) and illustrates a collapse for all A values at low-Ra. The grouping RaA^4 implies a modified Ra controlling this collapsed regime, which is expressed as

$$Ra_H = RaA^4 = \frac{g\alpha(\delta\theta_H)}{\upsilon\kappa_T}H^3 \qquad (1)$$

Here, $\delta\theta_H$ is the temperature difference along a portion of the bottom boundary of length H, which indicates that horizontal convection at very shallow enclosures will be controlled by the enclosure height and adjacent the horizontal temperature gradient at low-Ra. The horizontal velocity component and the temperature relative to a local bottom wall temperature of this collapsed regime are extracted at various location at the bottom boundary from the

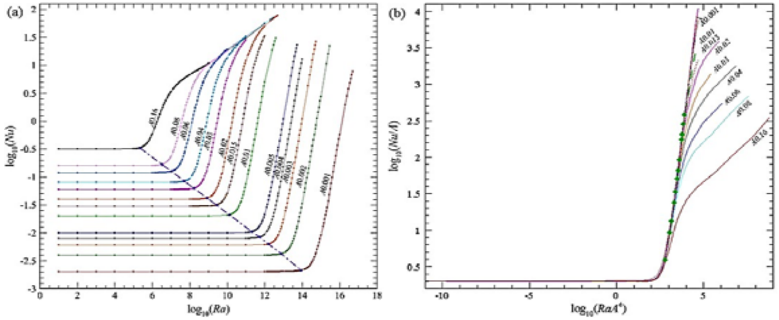

Figure 1: (a) $log\ Nu$ vs $log\ Ra$ is plotted for all aspect ratios, where the purple line marks the onset of transition regime. (b) Rescaled plot of (a), where the low- Ra values collapsed into a single curve.

hot sidewall of the enclosure. Polynomial fits to these velocity and temperature plots are found to agree with the obtained analytical solution for a 1D-channel flow driven by a linear temperature gradient. The analytical solutions for horizontal velocity U and temperature θ'S.H. is supported by MIPRS and MGS scholarships from Monash. This work was supported by the ARC Grants, titled DP150102920 and DP180102647, and was undertaken using NCI by a grant under the National Computational Merit Allocation Scheme (NCMAS).

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Brief Biography

Sajjad Hossain is a PhD student of Monash University studying natural convection flows. He completed BSc. in mechanical engineering from BUET, Bangladesh in 2011. His thesis was on CFD analysis of novel techniques to reduce friction factor in u-type wavy tubes. He worked as a project engineer in BanglaCAT, the largest electric power generation dealer for Caterpillar in the Asia Pacific, whereby he was engaged to design and installation of two 100 MW HFO-based power plants and over 30 gas and diesel captive power plants. He completed Masters from University of Malaya, Malaysia. There he conducted heat transfer and combustion analysis of renewable and sustainable fuels, like gas-to-liquid (GTL) and biodiesels. He has published 15 ISI Q1 journal papers in the field of energy and heat transfer.