Phenomenon of Ekman pumping in rotating Rayleigh-Bénard convection with boundary roughness

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In various astrophysical and geophysical flows natural convection occurs in the presence of rotation and boundary roughness. The present study tries to understand such flows, by focussing on the heat transfer measurement in rotating Rayleigh-Bénard convection (RRBC) with boundary roughness of tetrahedron geometry.

The experiments are performed with an in-house built turn table and rectangular RBC cell with boundary roughness $(k = 0.4)$ (see figure 1(a)) of aspect ratio $(\Gamma = D/H)$ 2.77, for no slip with isothermal and insulated, horizontal and lateral boundary conditions respectively. We use python version of the finite difference code SARAS[1] pySaras for our direct numerical simulation (DNS) with smooth boundaries. The heat transfer is characterised by Nusselt number $(\mathrm{Nu} = qH/\lambda\Delta T)$ is measured for Rayleigh number $(\mathrm{Ra} = \alpha g \Delta T H^3/\nu\kappa)$ 1.1×10^7 and 3.4×10^6 for various Rossby number $(\mathrm{Ro} = \sqrt{\alpha g \Delta T/H}/2\Omega)$. The results for RRBC with smooth (case I) and rough walls (case II) have been compared. We observe three regimes of heat transfer in both the cases (see figure 1(b)), that includes non-rotating or rotation un-affected (I), rotation affected (II), and Taylor-Proudman suppression regime (III). The heat transfer enhancement is attributed to the phenomenon of Ekman pumping[2,3]. The Ekman pumping occurs through columnar vortices spanning the depth of the RBC cell. The large temperature fluctuation in these vortices in presence of the boundary roughness and large Γ are perhaps attributed to the larger heat transfer enhancement (case II $\approx 27\%$) at relatively lower Ra than previous studies[2,3]. The heat transfer enhancement is large with boundary roughness (case II) as compared to smooth boundaries (case I) for same Ra. Please note that the error bars are smaller than the symbols.

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[1] Samuel et al., *The Journal of Open Source Software* (2021).
[2] Joshi et al., *J. Fluid Mechanics* (2017).
[3] Zhong et al., *Physical Review Letters* (2009).

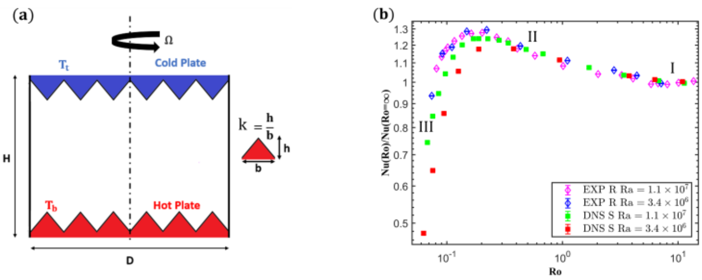

Figure 1: (a) Schematic of the RBC cell. (b) Variation of $\mathrm{Nu(Ro)/Nu(Ro = \infty)}$ with Ro. Here, $\mathrm{Pr} = 5.7$, $\Gamma \approx 2.77$, R and S denote rough and smooth boundaries respectively.