Non-Oberbeck-Boussinesq effects in highly turbulent Rayleigh-Bénard convection

Michal Macek*[1], Jakub Urban[1], Jan Rybka[1], Jiří Krempl[1], Jan Chládek[1], Věra Musilová[1], and Pavel Urban[1]

[1]Czech Academy of Sciences, Institute of Scientific Instruments – Czech Republic

Abstract

Rayleigh-Bénard Convection (RBC) experiments reaching very high Ra (1), approaching values relevant for
convective systems in Nature, were in the last decades performed using various working fluids, like cryogenic
helium 4He (2) or sulphur hexafluoride SF6 (3) in different laboratories, and provide unique insights into the
dynamics of this 'archetype of complex systems". In many of these experiments, reaching high Ra came at the
cost of operating close to either the saturated vapor curve (SVC) or the critical point (CP), where different types
of dynamics beyond the Oberbeck-Boussinesq (OB) approximation may play significant role.

In the first part of the talk, we overview the existing approaches to capturing non-OB effects in high Ra
RBC (4, 5, 6, 7, 8, 9). Subsequently, we introduce a parametrization of RBC equations of motion (10), inspired
by the first-order Taylor expansion of fluid properties by Gray-Giorgini (4) and discuss importance of the individual
terms for the temperature profile asymmetry. Further, we discuss maps of different contributions of NOB
effects to response parameters of RBC (bulk temperature Tc, Nusselt number Nu and Reynolds number Re) calculated
using the NOB-extended Grossmann-Lohse (GL) model introduced by Yik et al. (8, 11) for cryogenic
helium 4He for temperatures T in a range of between 4 and 6 K and pressures p between 0 up to 4 atm. We employ here strictly laminar boundary layers (BLs) in order to isolate the response modification solely due to NOB effects. Finally, we comment
on the possible influences of the non-normal non-linear transition in convective BLs (12, 13) evaluating
the corresponding shear Reynolds numbers.

The work has been supported by the Czech Science Foundation project No. 25-16812S and the Czech
Academy of Sciences and French CNRS Mobility Plus project No. CNRS-25-12.

*Speaker

References:
(1) G. Ahlers, S. Grossmann and D. Lohse, Rev. Mod. Phys., 81, 503 (2009).
(2) L. Skrbek and P. Urban, Journal of Fluid Mechanics, 785, 270 (2015).
(3) X. He, D. Funfschilling, H. Nobach, E. Bodenschatz and G. Ahlers, Phys. Rev. Letters, 108, 024502 (2012).
(4) D. D. Gray and A. Giorgini, Int. J. Heat Mass Transfer, 19, 545 (1976).
(5) P.-E. Roche, HAL open science, (2007), https://hal.science/hal-00180267v1
(6) Y. Burnishev, E. Segre and V. Steinberg, Phys. Fluids, 22, 035108 (2010).
(7) S. Horn, O. Shishkina and C. Wagner, J. Fluid Mech., 724, 175 (2013).
(8) H. Yik, V. Valori, S. Weiss, Phys. Rev. Fluids, 5, 103502 (2020).
(9) S. Weiss, M. Emran and O. Shishkina, J. Fluid Mech., 986, R2 (2024).
(10) M. Macek, G. Zinchenko, V. Musilová, P. Urban, and J. Schumacher, Phys. Rev. Fluids, 8, 094606 (2023).
(11) M. Macek et al., to be submitted.
(12) P.-E. Roche, New J. Phys., 22, 073056 (2020).
(13) D. Lohse, O. Shishkina, Rev. Mod. Phys., 96, 035001 (2024) and Physics Today, 76, 26 (2023).