Assessing non-Oberbeck-Boussinesq effects of convection in cryogenic helium

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Rayleigh-Bénard convection (RBC) at high Rayleigh (Ra) numbers represents one of the most important model systems to study turbulent convection [1]. Experiments reaching very high Ra, approaching values relevant for convective systems in Nature, like the atmospheric convection, have been performed using various working fluids, prominently with cryogenic helium ^{4}He [2] and sulphur hexafluoride SF_6 [3]. The goal of attaining high Ra often comes at the cost of breaking the Oberbeck-Boussinesq (OB) conditions at the phase boundaries or near the critical points of the working fluids. In particular, the recent analysis [4] of RBC experiments performed near the saturated vapor curves (SVC) in ^{4}He and SF_6 indicates that the heat transport measurements of the Nusselt number Nu(Ra), which apparently show the transition of RBC to the ultimate Kraichnan regime, are significantly affected by non-OB (NOB) effects, thus keeping the question of experimental observation of the ultimate regime open. The present study investigates the NOB effects which arise due to the temperature dependence of material properties in cryogenic helium experiments of turbulent RBC. The material properties such as specific heat at constant pressure, dynamic viscosity, thermal conductivity, the isobaric expansivity, and the mass density are expanded into power series with respect to temperature up to the quadratic order with coefficients obtained from the software package HEPAK. A subsequent nonlinear regression that uses deep convolutional networks delivers a dependence of the strength of NOB effects in the pressure–temperature parameter plane. Strength of the NOB effects is evaluated via the deviation of the mean temperature profile $\xi_{\mathrm{NOB}} \equiv T_m - T_c$ from the top/bottom-symmetric OB case $\xi_{\mathrm{NOB}} = 0$. Training data for the regression task are obtained from 236 individual long-term laboratory measurements at different Rayleigh numbers which span 8 orders of magnitude. The work has been supported by the Czech Science Foundation project No. 21-06012J.

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] P. Urban, P. Hanzelka, T. Králík, M. Macek, V. Musilová and L. Skrbek, *Phys. Rev. E*, **99**, 011101(R), 2019.

[5] D. D. Gray and A. Giorgini, *Int. J. Heat Mass Transfer*, **19**, 545, 1976.

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