Cryogenic Thermal Convection - Experimental Investigation

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Part 1

We present experimental results on heat transfer efficiency of cryogenic turbulent Rayleigh-Bénard convection (RBC) in a cylindrical cell 0.3 m both in diameter and height which has improvements with respect to various corrections connected with finite thermal conductivity of sidewalls and plates [1]. The heat transfer efficiency described by the Nusselt number $\mathrm{Nu} = \mathrm{Nu}(\mathrm{Ra},\mathrm{Pr})$ is investigated in the range of Rayleigh number $10^6 < \mathrm{Ra} < 10^{15}$, with the Prandtl number varying as $0.7 \leq \mathrm{Pr} < 15$, using cryogenic ^{4}He gas with well-known and *in situ* tuneable properties as a working fluid. For $7.2 \times 10^6 < \mathrm{Ra} < 10^{11}$ our data (both corrected and uncorrected) agree with suitably corrected data from similar cryogenic experiments and are consistent with $\mathrm{Nu} \propto \mathrm{Ra}^{2/7}$ [2]. Up to $\mathrm{Ra} \simeq 10^{12}$, our data could be treated as Oberbeck-Boussinesq. For $\mathrm{Ra} > 10^{12}$, the heat transfer efficiency becomes affected by non Oberbeck-Boussinesq (NOB) effects, causing asymmetry of the top and bottom boundary layers [3]. For $10^{12} \leq \mathrm{Ra} \leq 10^{15}$, the Nusselt number closely follows $\mathrm{Nu} \propto \mathrm{Ra}^{1/3}$ if Nu and Ra are evaluated based on the working fluid properties at directly measured bulk temperature, T_c, and suitable corrections are taken into account. In contrast, if the mean temperature is determined as an arithmetic mean of the bottom and top plate temperatures, $\mathrm{Nu}(\mathrm{Ra}) \propto \mathrm{Ra}^{\gamma}$ displays spurious crossover to higher γ that might be misinterpreted as a transition to the ultimate Kraichnan regime [4]. The second step of our analysis, reported here for the first time, is to ignore the NOB effects affecting the top half of the RBC cell. We replace it by the inverted nearly OB bottom half in order to eliminate the boundary layer asymmetry. This leads to the effective temperature difference, $\Delta T_{\mathrm{eff}} = 2(T_b - T_c)$, where T_b denotes the bottom plate temperature, and to effective $\mathrm{Nu}_{\mathrm{eff}}$ and $\mathrm{Ra}_{\mathrm{eff}}$ values [5]. The obtained effective heat transfer efficiency, showing no tendency of crossover to the ultimate regime up to 2×10^{15} in $\mathrm{Ra}_{\mathrm{eff}}$, is reported and discussed.

Part 2

When two bodies A and B of temperatures $T_A > T_B$ are thermally connected, heat flows from A to B - this statement is hardly surprising. But is it always true? We describe and discuss the opposite case, when *heat flows from a colder, constantly heated body B to a hotter, constantly cooled body A that are thermally connected via two-phase cryogenic helium.* More specifically, we provide an experimental evidence that heat flows from constantly heated but cooler bottom plate of the Rayleigh-Bènard (RB) convection cell, through liquid and gaseous layers of cryogenic helium, to its hotter top plate, cooled via a heat exchange chamber by a liquid helium vessel at 4.2 K above it. Additionally, for certain experimental conditions, we observe a process mimicking weather formation inside our RB cell - rain of helium droplets is detected by small sensors in the cell interior at about half of its height [6].

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