Ultimate heat transfer in convective turbulence with wall permeability

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Abstract

There is a difference in temperature between bulk fluid and a wall surface in thermal convection, so that heat is transferred between the fluid and the wall. Such heat transfer is dominated by thermal conduction on the wall where fluid velocity is null, although it highly depends on flow characteristics. In this talk, turbulent heat transfer in wall-bounded thermal convection is discussed with emphasis on the so-called ultimate state in which a wall heat flux is independent of thermal diffusivity, i.e. conduction anomaly (or anomalous scalar dissipation), and energy dissipation is independent of kinematic viscosity, i.e. the Taylor dissipation law implying inertial energy dissipation or anomalous energy dissipation. Feasibility of the ultimate heat transfer is explored numerically by the introduction of wall permeability in Rayleigh-Bénard convection. It is found that in turbulent thermal convection between the horizontal porous walls or the horizontal walls with an array of vertical rods installed, the ultimate heat transfer represented by the Nusselt number Nu_˜Ra^{1/2} can be achieved through the onset of large-scale thermal plumes even near the walls at high Rayleigh numbers Ra. At low Rayleigh numbers, however, vertical (wall-normal) fluid motion is not excited in the near-wall region despite wall permeability, so that the classical scaling Nu_˜Ra^{1/3} is observed. In between these two distinct scaling ranges of the Rayleigh number, we have found 'super-ultimate' behaviour given by Nu_˜Ra with the scaling exponent of unity being higher than that in the ultimate state. This super-ultimate scaling is considered to be a consequence of full excitation of large-scale thermal plumes comparable with those in the ultimate state and of less energy dissipation in the laminar or nearly laminar flow through the porous walls or between the rods than in the ultimate state at the high Rayleigh numbers. We present theoretical interpretations of the scaling laws not only for the ultimate state but also for the super-ultimate state.

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