Turbulent Thermal Convection over a Rough Surface

Submitted by
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FIG. 1.

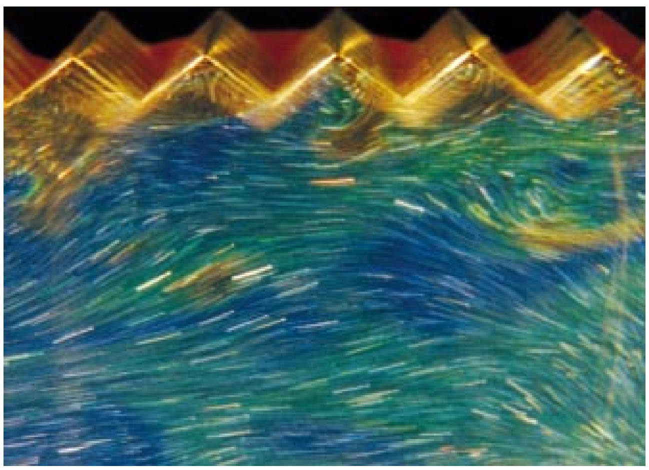

FIG. 2.

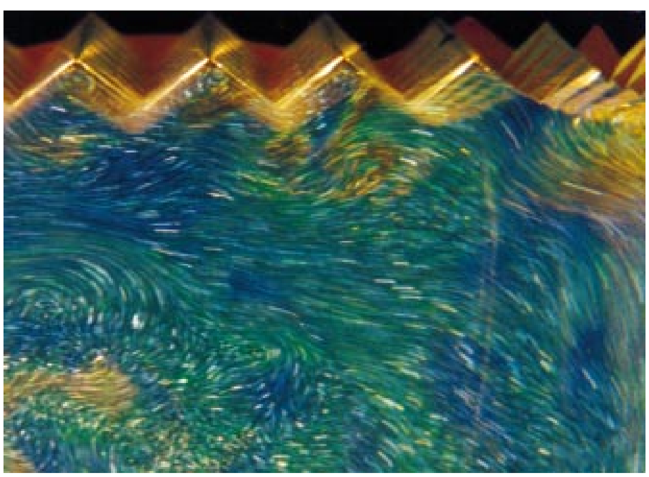

FIG. 3.

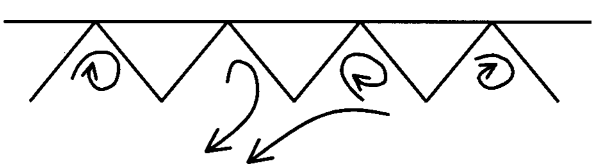

FIG. 4.

In these streak pictures of small seed thermochromic liquid crystal spheres, we show visualizations of the temperature and velocity fields near the upper (cold) surface of an aspect-ratio-one Rayleigh–Benard convection cell filled with water. Cooler regions of the fluid appear brown and warmer regions appear green and blue. Two cylindrical cells are used in the experiment; one has smooth upper and lower surfaces and the other has rough upper and lower surfaces. The rough surfaces are made from identical brass plates but have woven V-shaped grooves on them. The spacing between the grooves is such that a square lattice of pyramids of height 9 mm is formed on the surface. Figures 1 and 2 show how a cold plume erupts from the upper smooth and rough surfaces, respectively, at the Rayleigh number 2.6×10^9. In the smooth cell, the plume erupts by its own buoyancy, which accelerates the fluid in the central stem of the plume and produces a vortex ring around the stem. A two-dimensional projection of the vortex ring shows a pair of vortices with opposite signs, which gives the characteristic mushroom shape of the thermal plume.

In the rough cell, however, we find that the large-scale motion (from right to left) is modulated by the rough surface and produces an adverse pressure gradient in the groove region. This pressure gradient creates eddies whose vorticity is opposite to that of the large-scale circulation. As shown in Fig. 4, the interaction between the large-scale flow and the eddy causes the thermal boundary layer to detach near the tip of the pyramid. Because the detachment of the boundary layer is driven by the large-scale flow, instead of the buoyancy force, the vortex ring generated by the buoyancy acceleration disappears and thus the thermal plumes in the rough cell lose their mushroom cap. Occasionally, we do see a few mushroom-shaped plumes in the rough cell, such as that shown in Fig. 3, but the majority of the thermal plumes look like that shown in Fig. 2. The experiment reveals that the interaction between the large-scale flow and the eddies trapped inside the groove enhances the detachment of the thermal plumes. These extra plumes are responsible for the enhanced heat transport observed in the rough cell.[1,2]

[1] Y.-B. Du and P. Tong, ''Enhanced heat transport in turbulent thermal convection over a rough surface,'' Phys. Rev. Lett. **81**, 987 (1998).
[2] Y.-B. Du and P. Tong, ''Turbulent thermal convection in a cell with ordered rough boundaries,'' to appear in J. Fluid Mech.

