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Fluid Particles Irreversible in Some Circumstances, Physicists Report in Nature

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When a viscous fluid, such as a jar of honey, is stirred and then unstirred, the contents return to their starting points. However, according to research by a team of physicists headed by New York University's David Pine, the particles of such fluids do not always return to their original locations. The findings are reported in the latest issue of the journal *Nature*.

It is a well-established consequence of the laws governing fluid motion that when a viscous fluid is stirred and then unstirred, all parts of the liquid return to their starting points. Pine, along with his colleagues at the Haverford College (PA), the California Institute of Technology, and the Israel Institute of Technology in Haifa, examined what happens to the particles of such fluids during this process.

The researchers studied the movement of tiny polymer beads suspended in a viscous fluid trapped between two concentric cylinders. The cylinders were held 2.5 millimeters apart and could rotate relative to each other. Based on their experiments, the researchers observed that for low concentrations of beads stirred a short distance, the mixing can be reversed so that the beads return to their starting positions. However, at higher concentrations, or with more stirring, mixing became irreversible. The appearance of this irreversible behavior is caused by multiple encounters between individual beads, they concluded.

"The irreversibility of these particles may be explained by the extreme sensitivity of their trajectories to imperceptibly small changes of the particle positions," said Pine, director of NYU's Center for Soft Matter Research. "Such perturbations might arise from almost anything, such as small imperfections in the particles or by small external forces, and are magnified exponentially by the wakes particles sense due to the motion of other particles suspended in the liquid. Physical systems that exhibit such extreme sensitivity to small perturbations are said to be 'chaotic.' "

Pine also noted that the results "are interesting from a fundamental point of view because they demonstrate experimentally how vanishingly small perturbations of systems governed by deterministic equations can lead to stochastic non-deterministic behavior."

Mixing processes are difficult to scale up from laboratory bench to production plant because the change in their mixing behavior can be unpredictable. For example, poor understanding of particle migration during injection molding of precision ceramic parts limits manufacturing of large complex shapes. Understanding the influence of collisions between suspended particles may shed new light on the problem.

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