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Elastic flow instabilities in 3D porous media

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Many energy, environmental, industrial, and microfluidic processes rely on the viscous flow of polymer solutions through porous media. In many cases, the macroscopic flow resistance abruptly increases above a threshold flow rate in a porous medium—but not in bulk solution. The reason why has been a puzzle for over half a century. Here, by directly visualizing the flow in a transparent three-dimensional (3D) porous medium, we demonstrate that this anomalous increase is due to the onset of an elastic instability in which the flow exhibits strong spatio-temporal fluctuations reminiscent of inertial turbulence, despite the vanishingly small Reynolds number. We find that the transition to unstable flow in each pore is continuous, arising due to the increased persistence of discrete bursts of instability above an onset flow rate; however, this onset value varies from pore to pore. Thus, unstable flow is spatially heterogeneous across the different pores of the medium, with unstable and laminar regions coexisting. Guided by these findings, we quantitatively establish that the energy dissipated by unstable pore-scale fluctuations generates the anomalous increase in flow resistance through the entire medium. Thus, by linking the onset of unstable flow at the pore scale to transport at the macroscale, our work yields generally-applicable guidelines for predicting and controlling polymer solution flows. As a demonstration of this principle, we demonstrate how such elastic flow instabilities can be harnessed to homogenize flow and passive scalar transport in structurally heterogeneous porous media, beyond what is possible using traditional Newtonian fluids.

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References

C. A. Browne and S. S. Datta, "Elastic turbulence generates anomalous flow resistance in porous media", Science Advances, 7, eabj2619 (2021). URL: https://www.science.org/doi/10.1126/sciadv.abj2619

Time Block Preference

Time Block C (18:00-21:00 CET)

Participation

In person

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