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Topological phase transition in 2D porous media flows NICOLAS WAISBORD, Department of Mechanical Engineering, Tufts University, NORBERT STOOP, Department of Mathematics, MIT, VASILY KANTSLER, Department of Physics, University of Warwick, JEFFREY S. GUASTO, Department of Mechanical Engineering, Tufts University, JORN DUNKEL, Department of Mathematics, MIT, GUASTO TEAM, DUNKEL TEAM, KANTSLER TEAM — Since the establishment of Darcy's law, analysis of porous-media flows has focused primarily on linking macroscopic transport properties, such as mean flow rate and dispersion, to the pore statistics of the material matrix. Despite intense efforts to understand the fluid velocity statistics from the porous-media structure, a qualitative and quantitative connection remains elusive. Here, we combine precisely controlled experiments with theory to quantify how geometric disorder in the matrix affects the flow statistics and transport in a quasi-2D microfluidic channel. Experimentally measured velocity fields for a range of different microstructure configurations are found to be in excellent agreement with large-scale numerical simulations. By successively increasing the matrix disorder, we study the transition from periodic flow structures to transport networks consisting of extended high-velocity channels. Morse-Smale complex analysis of the flow patterns reveals a topological phase transition that is linked to a qualitative change in the physical transport properties. This work demonstrates that topological flow analysis provides a mathematically well-defined, broadly applicable framework for understanding and quantifying fluid transport in complex geometries.

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