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Humps, Spouts & Tendrils: Topological Transition Driven by Viscous Flow

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Viscous flows with large-scale spatial gradients can create small-scale structure on a steady-state interface separating two liquids. Here we focus on how an axisymmetric large-scale withdrawal flow in one liquid can break the interface between two liquids and thereby entrain a second liquid. Above the entrainment transition, thin spouts or tendrils of entrained liquid that persist over time form. Below the entrainment transition, the interface is deflected upwards by the flow and can form a hump with a strongly curved tip. To understand what mechanism allows a large-scale withdrawal flow to create small-scale feature on an initially flat interface, we analyze two simple scenarios. First, we consider the hump formed on an interface separating immiscible liquids. As the entrainment transition is approached from below, the minimum radius of curvature at the hump tip is determined by the maximum interface deflection height. Second, we consider the steady-state tendril formed on an interface between two miscible liquids. Again, the tendril radius is determined by the zero-entrainment deflection height of the interface.