Interfacial instabilities of bubbles in confined geometries

Anne Juel[1]

[1]*Manchester Centre for Nonlinear Dynamics and School of Physics & Astronomy, University of Manchester, Manchester, UK*

ABSTRACT

What links a baby's first breath to adhesive debonding, enhanced oil recovery, or even drop-on-demand devices? All these processes involve moving or expanding bubbles displacing fluid in a confined space, bounded by either rigid or elastic walls. In this talk, we show how spatial confinement may either induce or suppress interfacial instabilities and pattern formation in such flows. We demonstrate that a simple change in the bounding geometry of the containing vessel, e.g. a small height constriction within the cross-section of a rectangular channel, can radically alter the behavior of a fluid-displacing air bubbles and fingers. A rich array of propagation modes, including symmetric, asymmetric and localized fingers, is uncovered when air displaces oil from axially uniform tubes that have local variations in flow resistance within their cross-sections. An unexpected and novel propagation mode exhibits spatial oscillations formed by periodic sideways motion of the interface at a fixed relative distance behind the moving finger-tip. We apply these findings to passively sort bubbles by size. We support our experimental findings with a complementary analysis based on a depth-averaged theory. The theoretical study reveals that the exchange of stability between different modes of bubble propagation relies on non-trivial interactions between capillary and viscous forces.

Viscous fingering in Hele-Shaw cells is an archetype for front propagation and pattern formation: when air is injected into the narrow, liquid-filled gap between parallel rigid plates, the propagating air-liquid interface is unstable to deformation with a maximum unstable wavenumber set by the ratio of viscous to surface tension forces. We show how the introduction of wall elasticity (via the replacement of the upper bounding plate by an elastic membrane) can weaken or even suppress the fingering instability by allowing changes in cell confinement through the formation of axial depth gradients from the deflection of the membrane.