# Flow and instability induced by bubbles rising in a two-layer fluid system

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## ABSTRACT

Buoyancy-driven bubbles crossing horizontal liquid-liquid interfaces are encountered in a variety of engineering applications and natural settings such as wastewater treatment process and methane-emitting lakes. In these two-layer fluid systems, methane bubbles are generated in the lower layer due to biodegradation of organic material. The lower layer exhibits yield stress behaviour and is capped with water. The purpose of this study is to find the effect of the rheology of the lower layer on instability and turbidity driven by rising bubbles. The volume of viscoplastic fluid drawn into the upper layer is a quantity of primary interest. This volume may determine the efficiency of the aeration in the process of wastewater treatment, and the turbidity of the lakes.

Direct numerical simulations employing a volume-of-fluid type formulation combined with a quadtree adaptive mesh refinement technique are performed. The effect of the rheology of the lower layer on the volume of entrained fluid over a range of Archimedes number, density ratio, Bond number and viscosity ratio is explored. Our results show that as the bubble crosses the interface between two liquids tows a column of lower fluid that eventually breaks off into smaller droplets. We define the entrained volume as that of lower fluid located above the position of the initial horizontal interface. This volume consists of fluid trapped in the wake of bubble, the entrained column, and the fluid displaced at the liquid-liquid interface. In cases where either Bond number or Archimedes number is high, a larger volume of entrained fluid gets trapped in the primary/secondary wakes formed behind bubbles, see figure 1. By increasing the viscosity of the upper layer, the major contribution to the entrained volume comes from the region close to the liquid-liquid interface. Finally, the entrainment is categorized into three regimes based on the variation of entrained fluid as the bubble ascends. These were observed to be the ascending, descending, and plateau regimes. The viscoplastic entrainment mainly follows the plateau regime, suggesting that the yield stress of the entrained fluid resists the stress due to density difference between the fluid layers and thus remains unyielded.

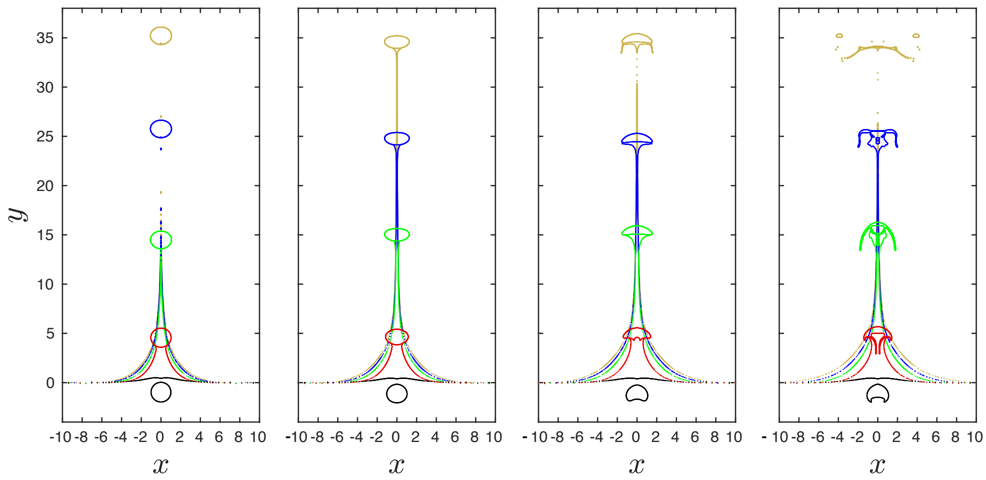

**Figure 1:** Spatiotemporal images of a bubble crossing the interface between a yield stress fluid (lower layer) and a Newtonian fluid (upper layer). The fluid are iso-dense and the viscosity of the upper layer is 0.1 of the plastic viscosity of the lower layer. The Archimedes number is 5, and the Bond number varies from left to right with values of 0.1, 1, 10, and 50. Since fluids are iso-dense, the Archimedes number varies by a factor of 100 due to the viscosity ratio, as the bubble crosses the interface and the Bond number remains unchanged. By increasing the Bond number, the volume of the lower fluid that bubble entrains increases. It is expected that a combination of strongly sheared and displaced interface, the higher the liquid column entrained and liquid trapped in the primary wake of bubble in the lower layer, contribute to an increase in entrained volume by increasing the viscosity of the upper fluid.