Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Yield Limit Analysis of a Single Bubble in Damaged Viscoplastic Fluids

Anita Hadizadeh[1*], Marjan Zare[2], Ian A. Frigaard[1,3]
[1]Department of Mechanical Engineering, University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[2]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[3]Department of Mathematics, University of British Columbia, Vancouver, BC V6T 1Z2, Canada

*anitaa99@mail.ubc.ca

Abstract

This study aims to address the environmental impact of greenhouse gas emissions from oil sands tailings ponds, where processing byproducts settle awaiting land reclamation. These tailings exhibit viscoplastic rheological behavior, allowing small gas bubbles to become either trapped or released into the atmosphere: the latter representing a significant environmental concern. Therefore, understanding the physics of gas bubble propagation in viscoplastic fluids is essential for addressing this issue. Previous research suggests that rising bubbles in yield-stress fluids create damaged pathways, which influence the trajectories of subsequent bubbles. These pathways, with or without water intrusion, create rheological non-uniformity, making predictions based on uniform fluid properties unreliable. To address these challenges, this study develops computational methods to determine the critical yield stress required to entrap buoyant bubbles in yield-stress fluids with damaged regions. A key computational challenge is accurately identifying unyielded regions within these flows. We address this by examining the buoyancy-driven motion of two-dimensional bubbles in a Bingham fluid using an augmented Lagrangian method. We explore the relation between mobility and resistance problems and derive general results on the static stability limit. The static limit is influenced by factors such as bubble shape, offset distance to damaged paths, the dimensionless surface tension and yield stress-to-buoyancy stress ratio. Our results show that even when a bubble is entirely trapped within a yield-stress fluid, the presence of a damaged layer enables the bubble to rise at higher yield numbers compared to uniform fluid conditions. We also explore whether extending the offset distance reaches a critical point beyond which the Newtonian layer no longer influences bubble motion.

We acknowledge financial support from NSERC and via Discovery grant RGPIN-2020-04471.