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On the capillary rise of cryogenic liquids in microgravity: numerical analysis and experiments

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Abstract

The spreading of liquids along solid walls is controlled by the capillary forces produced by the curvature of the gas-liquid interface. This curvature, in turn, depends on the dynamic contact angle (DCA) between the interface and the wall at the contact line. In low-gravity conditions, the importance of capillary forces (and thus the DCA) extends far away from solid walls as they are responsible for the transport of the liquids, using grooves or textured surfaces, and define where the free liquid surface is located in partially filled tanks. These factors are critical considerations in the design of fuel storage and delivery systems for space missions.
While Computational Fluid Dynamics (CFD) is commonly used to predict the behavior of cryogenic fluids in propellant management devices, there remain significant challenges in predicting the transient behavior of gas-liquid interfaces in microgravity conditions, especially for low viscosity and volatile fluids like cryogenics. In this work, we aim to improving the accuracy of CFD simulations by validating them against a new benchmark experiment described in [1]. The experiment involves the reorientation and capillary rise of liquid interfaces in a U-shaped divergent tube and provides high-speed visualizations of the gas-liquid interface and its DCA.
We use a VOF (Volume Of Fluid) solver from the finite volume libraries OpenFoam to reproduce the experiment. For that purpose, an experiment-driven DCA correlation is implemented, in order to determine the dominant mechanisms that drive the interface motion. We also explore the relationship between the chosen DCA correlation, the mesh resolution and the interface compression. Slip length models are employed to account for the divergence of viscous stress that arises from the use of DCA models.
The ultimate goal is to establish a simulation environment that allows identifying the dominant parameters to predict and control the position of the interface in capillary-dominated space applications.

References

[1] D. Fiorini, L. Carbonnelle, A. Simonini, J. Steelant, D. Seveno, and M. A. Mendez, “Capillary rise in Divergent U-Tube during parabolic flight,” in *27th European Low Gravity Research Association Biennial Symposium and General Assembly*, 2022, pp. 72–73.