Study on the Stability of Vertically Vibrating Liquid Layers: From Suspension to Multistate Instability

Hu, Hanwen (School: Chongqing Yucai Secondary School)

Tang, Zhichen (School: Chongqing Yucai Secondary School)

In a vertically vibrating environment, the dynamic behavior of liquids and bubbles differs from that in a static gravitational field. This study investigates the dynamic stability of a liquid–gas interface using a combined theoretical and experimental approach. A bubble dynamics model and a spring mass model of the levitated liquid layer were established to investigate the coupled effects of buoyancy, added mass force, drag force, and liquid inertia. The results show that the inertial force caused by vibration can effectively adjust the gravity of the system, thus inhibiting the development of interface disturbances and realizing dynamic stability. Experimentally, high-speed imaging captured the coupling between bubble motion and liquid-layer stability. Under certain vibration parameters, bubbles accumulate at the bottom, forming an air layer that acts as a gas spring. The observations show that under certain ranges of vibration parameters, bubbles change their conventional behavior of moving upward and instead move downward to accumulate at the bottom of the container. This creates a layer of air that has a significant buffering effect. This layer acts as a gas spring that absorbs the vibrations in the liquid, thereby reducing the amplitude of oscillation at its surface, which is very beneficial in increasing the stability of the levitated liquid layer. Interfacial morphologies were classified into three categories—stable, transitional, and unstable—comprising ten subtypes. This research uncovers the physical mechanism through which vertical vibration stabilizes an otherwise unstable inverted interface, and presents a unified framework to understand bubble layer coupling and its applications to spacecraft fuel management and multiphase flow control.

Awards Won: