Levitating Fluid Dynamics Under Vertical Vibration

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Vertical vibration can levitate a liquid layer above an air cushion. As the driving acceleration increases, the system transitions through three regimes: Rayleigh-Taylor instability at the lower interface, a stable levitation state, and Faraday instability at the upper interface. While previous studies have examined resonance behavior and partially described the onset of Rayleigh-Taylor instability, Faraday instability has not been sufficiently explored, and no unified framework has explained how both instabilities emerge and interact. This project developed a comprehensive theoretical model that captured the coupled dynamics of both interfaces and derived explicit stability boundaries as functions of driving acceleration, frequency, container geometry, fluid density, and viscosity. To test the theory, an experimental system was constructed to convert electrical signals into controlled vertical oscillations and enable high-speed visualization of interface motion. The experimental results confirmed the resonance behavior and showed a natural frequency of approximately 54 Hz in this system, significantly lower than values reported in earlier literature. Phase diagrams mapping stability regions also showed good agreement with theoretical predictions. Because the levitated film is fully supported and isolated by air, it avoids direct contact with solid surfaces. This offers potential applications in microfluidics and chemical processing, where reducing contamination, friction, and surface fouling remains a critical challenge.

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