Simulation of Acoustically Levitated Droplet under Isothermal Conditions

A Coupled Acoustic-Fluid Multiphysics Simulation

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Abstract

- To update acoustic field influence in real time during transient flow simulations, this study proposes a one-way coupling strategy based on the frequency-domain acoustic field.
- A 2D axisymmetric geometry is employed, where the "Pressure Acoustics, Frequency Domain" interface solves a 28.75 kHz ultrasonic standing wave field, yielding periodic steady-state sound pressure and particle velocity distributions.
- The acoustic radiation force is derived from the Gor'kov potential and applied as a custom volume force in the laminar flow interface. To accurately capture the surface effect of the radiation force, the built-in phase-field variable is introduced to confine the volume force strictly to a thin interfacial layer around the droplet. This strategy achieves high-accuracy acoustic-flow coupling while maintaining computational efficiency.

1 Research Background

An ultrasonic standing-wave levitator employs acoustic radiation force to levitate droplets without contact, eliminating wall interference. It provides an ideal platform for studying droplet dynamics under varying temperature and humidity, which has wide applications from biomedical to coating to energy field.

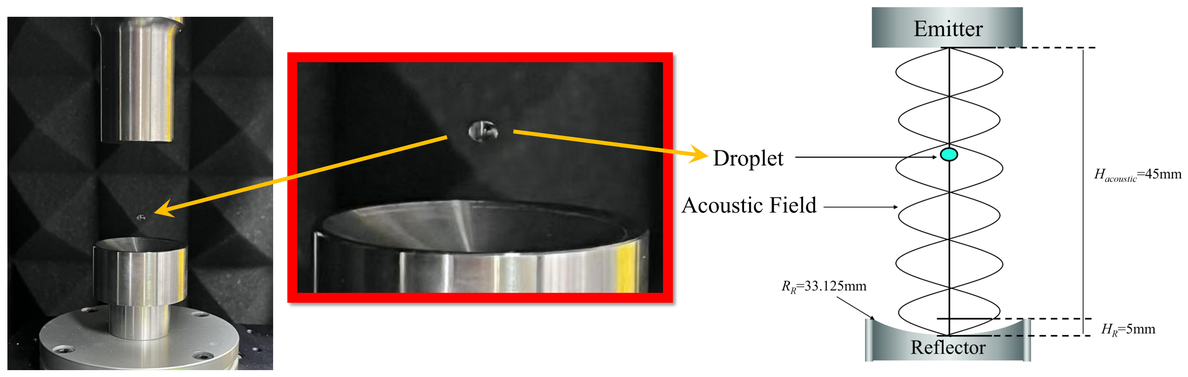


Fig. 1. Schematic diagram of ultrasonic standing wave droplet levitation.

2 COMSOL Multiphysics Model

The 2D axisymmetric domain couples the acoustic field, the surrounding air, and the droplets within it. Pressure acoustics and two-phase flow are solved simultaneously through fully coupled steady-state and transient studies.

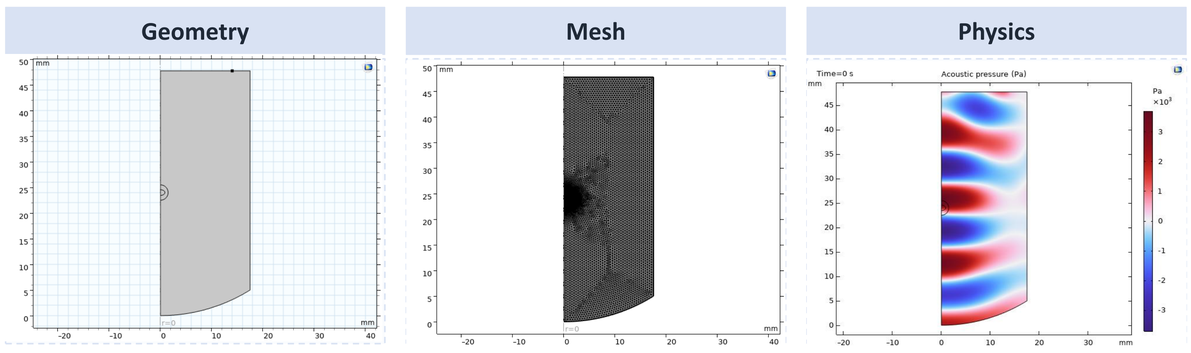


Fig. 2. Geometry, mesh and physics-interface setup of the coupled model.

3 Model Validation

28.8 kHz ultrasonic levitator // contactless 808 nm laser heating // synchronized high-speed/IR imaging to capture droplet deformation and temperature response, providing quantitative validation for COMSOL acoustic–flow–phase-field coupled simulation.

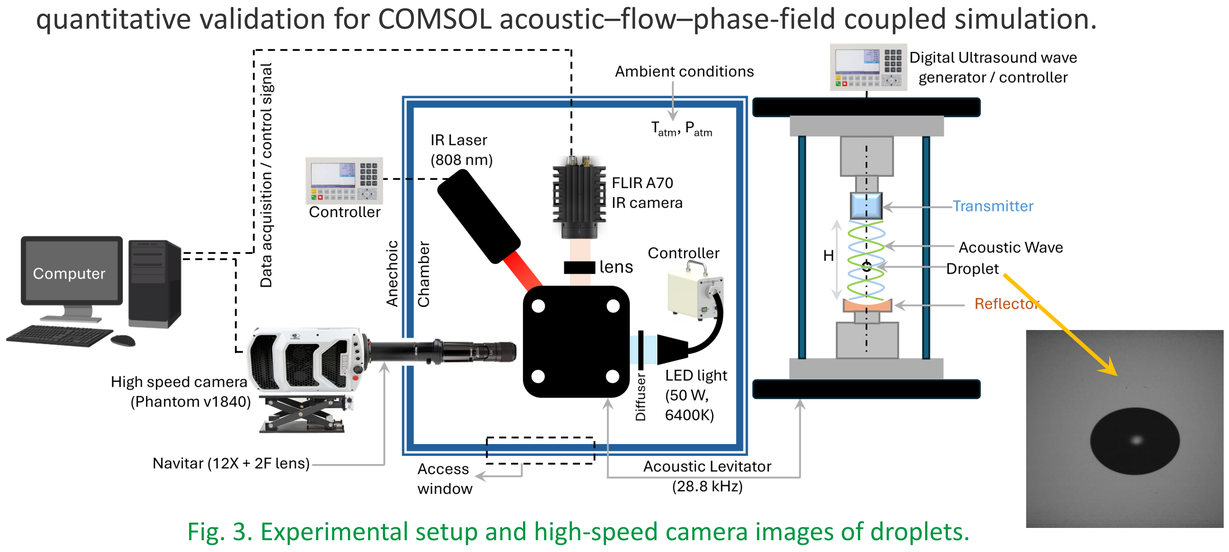


Fig. 3. Experimental setup and high-speed camera images of droplets.

4 Simulation Results

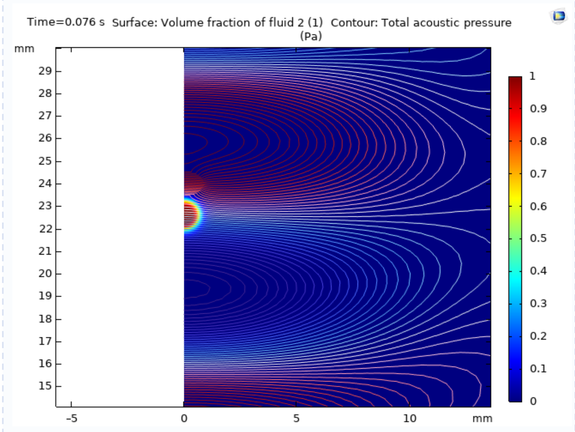


Fig. 4. Volume fraction and sound pressure plots

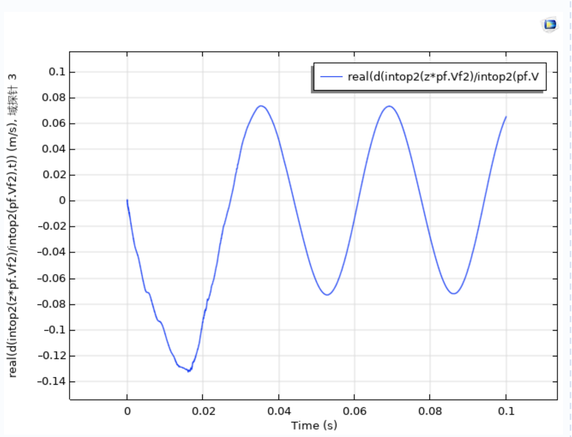


Fig. 5. Velocity changes during the droplet suspension process

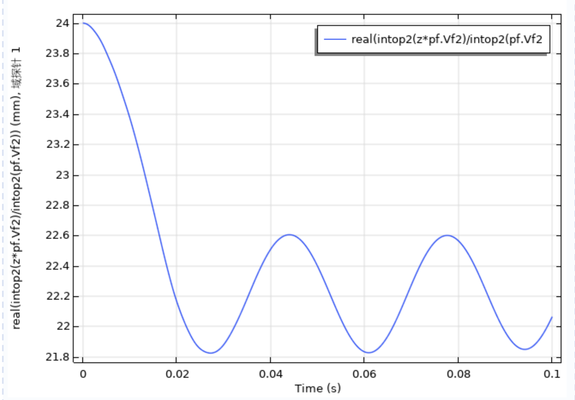


Fig. 6. During the levitation process, the droplet changes position and stabilizes at a pressure node.

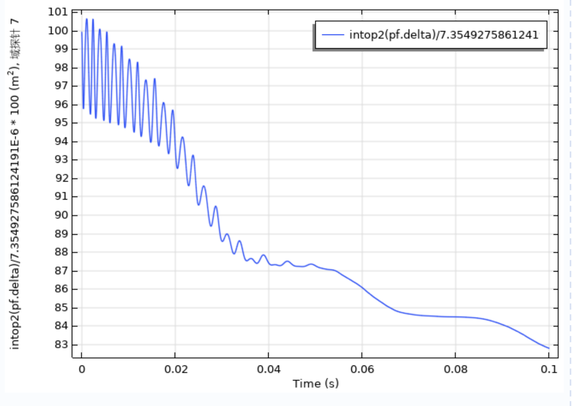


Fig. 7. Changes in interfacial parameters during the droplet suspension process

5 Discussion

The results show that the proposed strategy achieves,

- Stable droplet levitation in the ultrasonic field and reasonably reproduces interfacial dynamics.
- It should be noted that Gor'kov's radiation force treats the droplet as a rigid particle, predicting only the equilibrium position while failing to capture internal flow or interfacial phenomena such as deformation, splitting, and coalescence. Nevertheless, adopted here for numerical stability.
- Future work will incorporate the impedance-based body force, $f_a = -2kE_a \sin(2ky)\,\hat{Z}\,e_y$ (Eq. 3) and extend the framework—validated against experiments—to the evaporation of laser-heated fuel droplets of various materials under acoustic levitation.

6 Conclusions

- The simulation results show that the proposed modeling strategy enables stable droplet levitation in the acoustic field.
- The model successfully reproduces interfacial dynamics of the levitated droplet to a reasonable extent.
- The feasibility of the "frequency-domain one-way coupling + custom acoustic radiation force" approach for droplet levitation simulation is qualitatively validated with experimental observations.

References

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[2] M. Settles and A. Scheer, Eds., Ultrasonic Droplet Levitation and Contactless Manipulation, Berlin: Springer, 2020.
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Acknowledgment: This research is supported by the Sustainable Energy Technologies Lab, Guangdong Technion-Israel Institute of Technology, China.

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