JASMAC

Conference of the Japan Society of Microgravity Application

P26

温度差マランゴニ効果に起因する長液柱内における粒子集合現象の形成原理の実験的探究

Exploration of Formation Principle of Particle Accumulation Structure (PAS) in High-aspect-ratio Liquid Bridge Induced by Thermocapillary Effect

泉水将吾 [1]，野口信 [1]，黒瀬築 [2]，上野一郎 [2]

Shogo SENSUI[1], Shin NOGUCHI[1], Kizuku KUROSE[2] and Ichiro UENO[2]

[1] 東京理科大学大学院，Tokyo University of Science

[2] 東京理科大学，Tokyo University of Science

We investigate experimentally so-called particle accumulation structure (PAS) after Schwabe et al.[1)], in which tiny tracer particles accumulate to form coherent structures under certain conditions in the half-zone liquid bridge. In the half-zone liquid bridge (see **Fig. 1.**), a designated temperature difference ΔT $(\equiv T_\mathrm{h} - T_\mathrm{c})$ is imposed between the both end surfaces of the liquid bridge to generate thermocapillary-driven flow on the free surface. As ΔT is increased, the convection field in the liquid bridge exhibits a transition from two-dimensional steady state to three-dimensional 'oscillatory' one. After the pioneering work[1)], the spatial-temporal structure of the PASs and their occurring conditions have been investigated via experimental[2-6)] and numerical[7-9)] approaches. Such unique structures have been realized notwithstanding the gravitational acceleration condition[2,3,6)]. It has been indicated that the PAS exhibits a closed structure with an azimuthal wave number corresponding to those by the oscillatory flow by the hydrothermal wave instability[2)]. Their formation mechanism, however, has not been hitherto unveiled. Two major models have been proposed: particle-free surface interaction (PSI) model[10)] and phase locking model[11)]. The former implies the transfer of the streamlines to follow by the tiny particles near the free surface governs the formation of the PAS. The latter whereas implies the "synchronization" between the turnover motion of the particles and the azimuthal traveling flow in the liquid bridge realizes the particle accumulation.

In the present study, we conduct a series of on-ground experiments to investigate the correlation between the particle turnover motion and the traveling thermal flow with the spatial-temporal data of the particles forming the coherent structure inside the liquid bridge of O(1 mm) in size to overcome the static pressure under the normal gravity. The spatial-temporal behaviors of the suspended particles forming the PASs of various m's are monitored via the particle tracking velocimetry (**Fig. 2.**). We evaluate the Doppler shift[11)], and will discuss the validity of their model by the monitored experimental data themselves. We further investigate the occurring condition of the PASs by applying imaginary azimuthal traveling wave to the turnover motions of particles to propose a criterion to realize such coherent structures in the closed system.

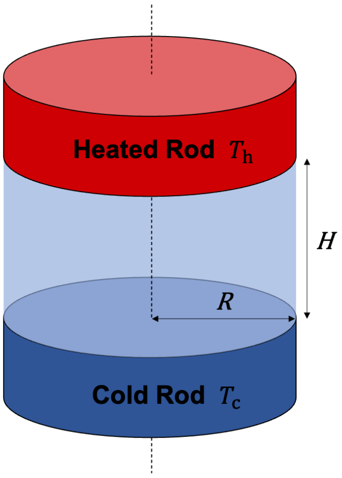

Figure 1. Half-zone liquid bridge.

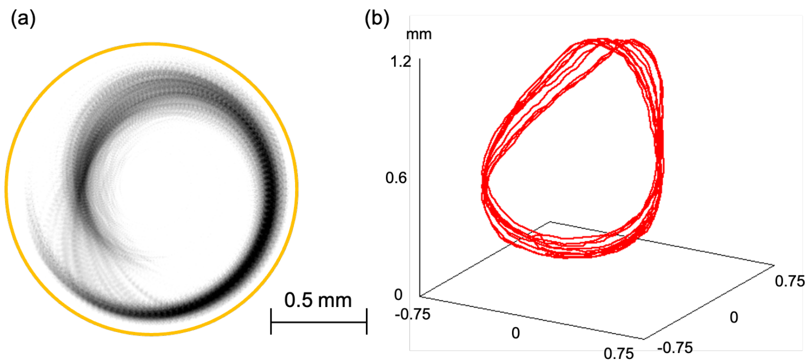

Figure 2. (a) Particle image taken from above liquid bridge in rotating frame of reference (black dots: particle, yellow circle: rod periphery) and (b) three-dimensional trajectory of particles forming coherent structure under $\Gamma\ (\equiv H/R) = 1.6$ and $\Delta T = 11$ K.

Acknowledgment

This work was partially supported from the Japan Society for the Promotion of Science (JSPS) by Grant-in-Aid for Challenging Research (Exploratory) (grant number: 20K20977).

References

1) D. Schwabe, New feature of thermocapillary convection in floating zones revealed by tracer particle accumulation structure (PAS), Microgravity Sci. Technol, **9** (1996) 163.
2) S. Tanaka, H. Kawamura, I. Ueno and D. Schwabe, Flow structure and dynamic particle accumulation in thermocapillary convection in a liquid bridge, Physics of Fluids, **18** (2006) 067103, DOI : 10.1063/1.2208289.
3) D. Schwabe, A. I. Mizev, M. Udhayasankar, and S. Tanaka, Formation of dynamic particle accumulation structures in oscillatory thermocapillary flow in liquid bridges, Phys. Fluids, **19** (2007) 072102, DOI : 10.1063/1.2742304.
4) M. Gotoda, A. Toyama, M. Ishimura, T. Sano, M. Suzuki, T. Kaneko and I. Ueno, Experimental study of coherent structures of finite-size particles in thermocapillary liquid bridges, Phys. Rev. Fluids, **244** (2019) 299, DOI : 10.1103/PhysRevFluids.4.094301.
5) T. Oba, A. Toyama, T. Hori and I. Ueno, Experimental study on behaviors of low-stokes number particles in weakly chaotic structures induced by thermocapillary effect within a closed system with a free surface, Phys. Rev. Fluids, **4** (2019) 104002, DOI : 10.1103/PhysRevFluids.4.104002.
6) T. Sakata, S. Terasaki, H. Saito, S. Fujimoto, I. Ueno, T. Yano, K. Nishino, Y. Kamotani and S. Matsumoto, Coherent structures of m = 1 by low-Stokes-number particles suspended in a half-zone liquid bridge of high aspect ratio: Microgravity and terrestrial experiments, Phys. Rev. Fluids, **7** (2022) 014005, DOI : 10.1103/PhysRevFluids.7.014005.

7) I. Barmak, F. Romano and H. C. Kuhlmann, Finite-size coherent particle structures in high Prandtl-number liquid bridges, Phys. Rev. Fluids, **33** (2021) 19, DOI : 10.1103/PhysRevFluids.6.084301.
8) P. Capobianchi and M. Lappa, On the influence of gravity on particle accumulation structures in high aspect-ratio liquid bridges, J. Fluid Mech., **908** (2021) A29, DOI : 10.1017/jfm.2020.882.
9) D. Melnikov, D. Pushkin, and V. Shevtsova, Accumulation of particles in time dependent thermocapillary flow in a liquid bridge: modeling and experiments, Euro. Phys. J. Spec. Topics, **192** (2011) 29, DOI : 10.1140/epjst/e2011-01357-7.
10) H. C. Kuhlmann and E. Hofmann, The mechanics of particle accumulation structures in thermo-capillary flows, Euro. Phys. J. Spec. Topics, **192** (2011) 3, DOI : 10.1140/epjst/e2011-01355-9.
11) D. Pushkin, D. Melnikov and V. Shevtsova, Ordering of small particles in one-dimensional coherent structures by time-periodic flows, Phys. Rev. Lett., **106** (2011) 234501, DOI : 10.1103/PhysRevLett.106.234501