Summary report of the ISS-Kibo utilization mission, "Chaos, Turbulence and its Transition Process in Marangoni Convection (Marangoni Exp/MEIS)"

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Feb, 2017

1. Abstract

This report summarizes the scientific outcome of five series of space experiments, called Marangoni Experiment in Space (MEIS), which were conducted from August 2008 through February 2013. Nearly four years have passed since the last series, MEIS-5, was completed, and some comprehensive reports and articles on the academic outcome of MEIS can be found in the special issues of academic journals such as follows:

#1 Special Articles 1: MEIS Marangoni Experiment in Space, Journal of The Japan Society of Microgravity Application, Vol. 26, No. 3, pp. 150-190 (2009) [41 pages] (in Japanese),
#2 Special Articles: Fluid Experiments on the Japanese Experiment Module “Kibo” of the International Space Station, Journal of the Japan Society of Fluid Mechanics “NAGARE”, Vol. 30, No. 1, pp. 3-24 (2011) [21 pages] (in Japanese), and
#3 Special Articles: MEIS (Marangoni Experiment in Space), International Journal of Microgravity Science and Application, Vol. 21, Supplement, pp. S2-S79 (2014) [78 pages] (in Japanese).

This report therefore describes only the representative scientific achievements that were already reported in a total of 32 journal publications.

2. Objectives of MEIS

(1) Transition to oscillatory state

Critical conditions for the transition from steady to oscillatory states and oscillation modes are clarified. The reported dependency of the critical Marangoni number on the size of the liquid bridge observed in some past microgravity experiments conducted in sounding rockets and space shuttles are examined. Critical conditions for long liquid bridges that cannot be generated on the ground are determined and compared with the theoretical values obtained for infinite liquid bridges. Critical conditions are also determined for high Prandtl number liquid bridges because their critical conditions are quite difficult to realize on the ground. Effects of heating rate and volume ration on the critical conditions are also experimented.

(2) Chaos and turbulence

Transitions to chaotic states are observed at high Marangoni number conditions of large liquid bridges that need long-term microgravity environment. The characteristics of the transition are quantified through measurements of three-dimensional flow, surface temperature and surface velocity.

(3) Particle accumulation structure (PAS)

Three-dimensional structures of PAS are observed at much higher Marangoni conditions than those realized on the ground. The effects of liquid bridge size and particle size on the PAS formation are examined.

3. Scientific success criteria and status of achievement

Success level	Criteria	Status	Basis
Minimum Success	✓ To determine critical temperature differences for the onset of oscillatory state for a wide range of aspect ratio of liquid bridge.	◎	✓ Critical temperature differences are determined for a wide range of aspect ratio (0.1 - 2.0) within 10% uncertainty. ✓ Successful determination for this aspect ratio range is possible only in MEIS.
Full Success	✓ To determine azimuthal mode numbers and structures of oscillatory flows and to clarify the transition of oscillation modes at high aspect ratio. ✓ To observe transition process of convection and transition to chaotic/turbulent flows at Marangoni numbers up to several times higher than the critical value. ✓ To examine the formation of PAS in large liquid bridge and to observe its structural characteristics.	◎	✓ The relation between aspect ratio and azimuthal mode number is clarified and longitudinal roll structures at high aspect ratios are revealed using 3-D particle tracking method and surface temperature propagation analysis. ✓ Transition processes at high Marangoni numbers up to twelve times the critical value are observed and their detailed characteristics are revealed using chaos analysis based on the Lyapunov exponent and the translation error. ✓ PASs are generated in large liquid bridges at conditions different from those in the ground experiments and their structural characteristics are analyzed.
Extra Success	✓ To see if the azimuthal mode number=0 appears or not at high aspect ratio. ✓ To observe Marangoni convection and PAS formation in droplets in space.	○	✓ The azimuthal mode number=0 .is not observed. ✓ Generation of semispherical droplets and reformation of liquid bridge are made, leading to the successful observation of Marangoni convection and PAS formation in the droplets.

4. Publications

	Direct contents	Related contents
Journal papers	32 papers (incl. 25 IF journals)	26 papers (incl. 26 IF journals)
Conference papers	68 papers	35 papers
Articles and books	20 articles and 1 book	3 articles
Patent applications	2 applications	―
Press releases	18 press releases	―