JASMAC Conference of the Japan Society of Microgravity Application

P21

温度差マランゴニ効果によって誘起される自由液膜内マルチセルラー構造に関する実験的研究

Experimental Study on Multicellular Structure Induced by Thermocapillary Effect in Free Liquid Film

山下凱也 [1], 川津晃貴 [1], 塚原隆裕 [2], 黒瀬築 [2], 上野一郎 [2]
Tokiya YAMASHITA[1], Koki KAWAZU[1], Takahiro TUKAHARA[2], Kizuku KUROSE[2] and Ichiro UENO[2]
[1] 東理大院, Tokyo Univ. Science
[2] 東理大, Tokyo Univ. Science

Thermocapillary-driven flow in a free rectangular liquid film (i.e., liquid film with two gas-liquid interfaces in a rectangular hole) under a temperature gradient parallel to the free surfaces is investigated experimentally. Pettit, a NASA astronaut, conducted a series of experiments on the International Space Station (ISS) in 2003 [1]. Among the variety of demonstrations, he formed a thin free liquid film of drinking water inside a ring of metal wire, and placed a heated iron close to one side of the ring. He indicated the fluid was driven toward the heated area. This apparently strange phenomenon led to extensive research on the induced flow in the free liquid film. After this on-orbit experiment, Ueno and Torii [2] revealed there exist two major basic flow patterns in the rectangular free liquid film (**Fig. 1.**) depending on their aspect ratios: double-layered flow (DLF) and single-layered flow (SLF). The shapes of liquid film is described by the two types of the aspect ratio, Γ_{xy} ($\equiv L_x/d$) and Γ_{zx} ($\equiv L_z/L_x$), and the volume ratio V/V_0, where V is the volume of the liquid film itself and V_0 is the volume of the hole to sustain the liquid film ($= L_x d L_z$). Experimental investigation indicated that the direction of the flow induced by the thermocapillary effect is dominated by the volume ratio of the free liquid film [3], and the cross-sectional flow structure of the single-layered flow as well as the double-layered flow [4]. Such effect was discussed via numerical simulations[5-7] and physical model[8] as well.

In the present study, we focus on multi-cellular structures in SLF in the free liquid films of varying aspect ratios. We form a rectangular free liquid film of 6-cSt silicone oil. For visualization of the flow field, gold-nickel-alloy coated acrylic particles are suspended as tracers. Marangoni convection is generated by providing designated temperature difference between the both ends of the free liquid film, one side of the plate with a rectangular hole is heated by a cartridge heater, and the other side is cooled by applying the cold liquid flow in a channel drilled in the sustaining block from a constant temperature bath. The temperature distribution on the free surface is monitored by an IR camera from above the free liquid film, and the particle motion is monitored using a high-speed camera from beneath the free liquid film via a cubic mirror. We successfully indicate that the induced flow exhibits a different number of cell structures depending on the aspect ratio of the liquid film (**Fig. 2.**). We illustrate the correlation among the non-dimensional wave number, the visualized particle motion, and the aspect ratio.

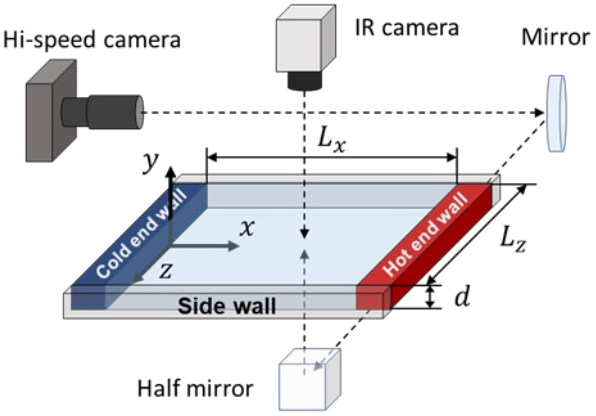

Figure 1. Schematic of experimental apparatus.

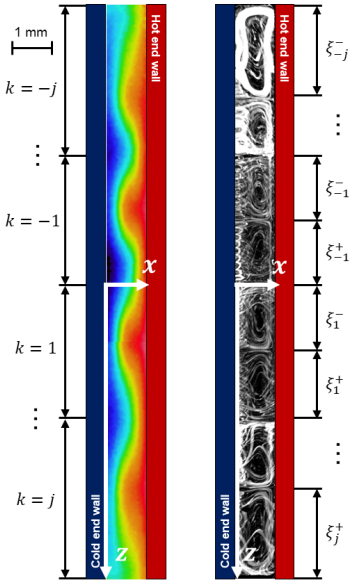

Figure 2. Temperature distribution and particle trajectory line in free liquid film ($\Gamma_{zx} = 14$, $V/V_0 = 0.9$).

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) https://forum.nasaspaceflight.com/index.php?topic=27587.0 (cited: the 21st Jul. 2022)
2) I. Ueno and T. Torii: Thermocapillary-driven flow in a thin liquid film sustained in a rectangular hole with temperature gradient, Acta Astronautica, **66** (2010) 1017, DOI: 10.1016/j.actaastro.2009.09.027.
3) I. Ueno, T. Katsuta, and T. Watanabe: Flow patterns induced by thermocapillary effect in thin free liquid film accompanying with static/dynamic deformations, Proc. Second Euro. Conf. on Microfluidics (2010), μFLU10–203.
4) L. Fei, K. Ikebukuro, T. Katsuta, T. Kaneko, I. Ueno and D.R. Pettit: Effect of static deformation on basic flow patterns in thermocapillary-driven free liquid film, Microgravity Sci. Technol., **29** (2017) 29, DOI: 10.1007/s12217-016-9523-8.
5) T. Yamamoto, Y. Takagi, Y. Okano and S. Dost: Numerical investigation for the effect of the liquid film volume on thermocapillary flow direction in a thin circular liquid film, Phys. Fluids, **25** (2013) 082108, DOI: 10.1063/1.4818160.
6) T. Yamamoto, Y. Takagi, Y. Okano and S. Dost: A three-dimensional simulation of thermocapillary flow in a circular thin liquid film under zero gravity, Trans. JSASS Aerospace Tech. Japan, **12** (2014) Pe19, DOI: 10.2322/tastj.12.Pe_19.
7) T. Yamamoto, Y. Takagi, Y. Okano and S. Dost: Numerical investigation of the effect of free surface shape on the direction of thermocapillary flow in a thin circular pool, J. Chemical Engineering of Japan, **48** (2015) 407, DOI: 10.1252/jcej.14we141.
8) H.C. Kuhlmann: Large-scale liquid motion in free thermocapillary films, Microgravity Sci. Technol., **26** (2014) 397, DOI: 10.1007/s12217-014-9404-y