A cognition on oscillatory mechanism of thermocapillary convection

Ruquan Liang* and Yanyan Zhang†

* Key Laboratory of National Education Ministry for Electromagnetic Processes of Materials,
Northeastern University
No.3-11, Wenhua Road, Shenyang 110819, China
e-mail: liang@epm.neu.edu.cn

† Liaoning Chenhan Law Firm,
No.333, Fengtian Street, Shenyang 110013, China
e-mail: Yyzhanglawyer@163.com

ABSTRACT

In air-liquid or liquid-liquid systems, the effects of evaporation, dissolution, migration of surfactant or temperature difference on the surface may lead to the emergence of surface tension gradient which induces spontaneous surface motion (such as surface deformation, the surface flow). In general, such surface motion magnified by the tractive action of surface flow is defined as Marangoni effect. Marangoni convection is one kind of natural convection, independent of gravity. The modern space experiments and numerical studies show that when the temperature difference exceeds a certain threshold, the oscillatory thermocapillary convection appears and the symmetry steady flow transforms into the asymmetric oscillatory flow. However, the oscillatory thermocapillary convection in melts may induce the striation formation during crystal growth and affect the quality of crystal growth.

In this paper, a direct numerical simulations (DNS) on oscillatory thermocapillary convection in a liquid bridge of high Pr fluids under normal gravity has been conducted by using a new method for capturing any micro-scale migrations of free surface. Against the former studies, the oscillatory behaviors of velocity, temperature, and free surface have been quantitatively investigated simultaneously. The present results show that the velocity oscillation is mainly affected by the interior flow variation in the liquid bridge, and there is a time lag in space between the surface flow and the return flow. The temperature oscillation is directly affected by the thermal disturbance at the hot corner, and the velocity oscillation responds slowly to the temperature oscillation. Further, the propagation directions of velocity and temperature oscillations are opposite, and complex coupling effects of two oscillations excite the oscillation of free surface. Therefore, the present results show that the instability of thermocapillary convection results from the interaction of free surface, velocity and temperature oscillations at the hot corner, and the coupling effects of three oscillations induce the asymmetric flow of thermocapillary convection. In addition, it is found that the high frequency oscillation exists at the mid-height of the surface by comparing the oscillations at the hot corner with that at the mid-height of free surface. A mechanism model of oscillatory thermocapillary convection for high Pr fluids is summarized and some peculiar phenomena are found. These findings are useful not only to the research on the thermocapillary convection but also to the theoretical basis for the nonlinear dynamic system control and the study on complex behavior in chemical and biological systems.

REFERENCES

[1] A. Wang, Y. Kamotani, S. Yoda, *et al*., "Oscillatory thermocapillary flow in liquid bridges of high Prandtl number fluid with free surface heat gain", *Int. J. Heat Mass Trans.*, **50(21-22)**, 4195–4205 (2007).

[2] S. Tiwari and K. Nishino, "Numerical study to investigate the effect of partition block and ambient air temperature on interfacial heat transfer in liquid bridges of high Prandtl number fluid", *J. Crys. Growth*, **300(2)**, 486-496 (2007).