Three Dimensional Flow Instabilities in Thermocapillary Flow in Annular Pool

Nobuyuki Imaishi[1], Michael Ermakov[2] and Wanyuan Shi [3]

1) Kyushu Univ., 6-1 Kasugakoen, Kasuga, 816-8586, Japan, imaishi@cm.kyushu-u.ac.jp
2) Inst. Problems in Mechanics, Moscow, Russia, ermakov@ipmnet.ru
3) Chongqing Univ., Chongqing, China, shiwy@cqu.edu.cn

Instability of thermocapillary flow in annular pool has been extensively investigated in these few decades. Annular pool attracts researcher's interests because of the following reasons: the geometry is somewhat similar to the Czochralski crystal grower and the geometry is completely free of the side walls. There are so many experimental and numerical investigations in this field, however, these works covered very limited range of parameters and the characteristics of the thermocapillary flow instabilitiy in annular pool are still left unclear. In the present work, a set of linear stability analyses was conducted to clarify the critical conditions for the onset of 3 dimensional instabilities and pattern formation in thermocapillary and buoyant-thermocapillary flows in annular pools of silicone oil (Pr=6.7) over a wide range of aspect ratio, different gravity levels and heating directions. The cavity is composed of an outer wall (Ro=40mm), an inner wall (Ri=20mm), adiabatic top surface and adiabatic solid bottom, and its depths d ranges from 0.2mm to 20mm (the aspect ratio $\Gamma=(Ro - Ri)/d$ ranging from 1 to 100). In this work, we use following non-dimensional variables $r=R/d$, $z=z/d$, $\mathbf{V}=\mathbf{v}d/\nu$, $\tau=t\nu/d^2$, $P=d^2p/\rho\nu^2$, $\Gamma=\Delta R/d$, $\Theta=\Gamma(T-T_c)/\Delta T$ and parameters $Re=\gamma_T\Delta Td^2/\mu\nu\Delta R$, $Gr=g\rho_T\Delta Td^4/\nu^2\Delta R$, $Bo_d=Gr/Re=g\rho_T d^2/\gamma_T$,, where $\Delta T=To-Ti$ is the temperature difference between the two solid walls and Re, Gr and Bo_d is the Thermocapillary-Reynolds, Grashof and Dynamic Bond numbers, respectively. Fig. 1 and Fig. 2 show the thermocapillary-Reynolds number for the incipience of 3-D disturbances as a function of the aspect ratio for ΔT>0 (heated from the outer wall) under 0G and 1G, respectively. The solid keys correspond to the critical condition and the open keys to the neutral stability limits. Some of the perturbation temperature patterns on the surface are also shown in the figures.

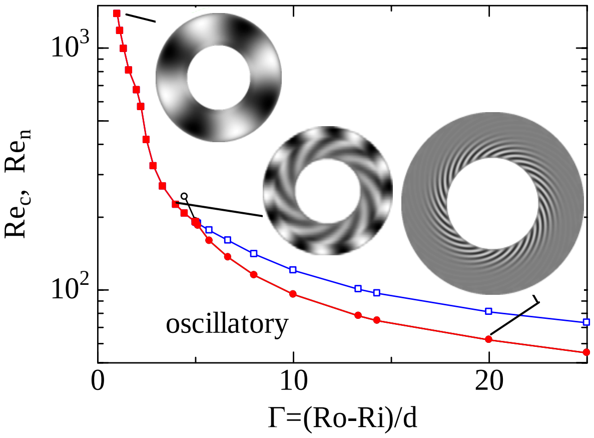

Fig. 1 The neutral and critical Reynolds number as a function of the aspect ratio for 0G. Surface temperature pattern are shown.

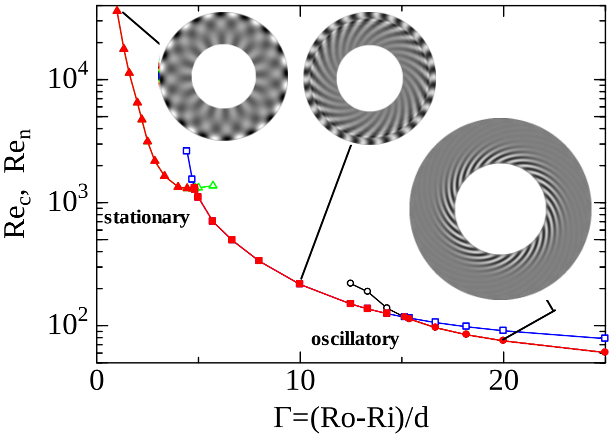

Fig. 2 The neutral and critical Reynolds numbers as a function of the aspect ratio for 1G. Surface temperature patterns are shown.

These results indicate that 1) the buoyancy stabilizes the basic flow field, 2) flow mode changes at certain liquid depths (d*), 3) stationary instability becomes dominant in deep pools under 1G. It should be noted that degeneracy of flow modes (two different flow modes with different wave numbers become unstable at the same ΔT) always occurs at the depth d*. In liquid pools of depth close to d*, two different patterns can coexist at slightly super critical conditions. This result can explain some experimentally observed phenomena.