THERMOCAPILLARY FLOWS STABILITY IN FLOATING ZONE UNDER MICROGRAVITY

O. Bouizi, C. Dang Vu-Delcarte, G. Kasperski
Université Paris-Sud XI, LIMSI-CNRS, B.P. 133, 91403 Orsay, Cedex, France
obouizi@limsi.fr, delcarte@limsi.fr, G. Kasperski@limsi.fr/Fax:+33(0)169858088

The floating zone is a crucible-free process used to produce high-quality crystals. A molten zone is created by a lateral heating between a feed and a single crystal rod, and helds by capillary forces. The translation of the material through the heat flux induces the solidification of the crystal. Temperature gradients induce surface tension variations which are the source of thermocapillary convection. In order to reduce buoyancy effects, experiments have been performed in a low gravity environment [7] and have demonstrated that thermocapillary convection alone can induce defects in the product due to flow instabilities. A major goal is to identify the mechanisms leading to the growth of those instabilities.

The experimental difficulty comes from the fact that measurements in the core of the flow are usually limited to transparent fluids, that is having a Prandtl number value (Pr), ratio of the characteristic thermal to dynamical diffusion times, larger than 6 or so. However, it has been shown that, just as well in real experiments as in numerical experiences, performed on the simplified *half-zone* model, the transitions thresholds strongly depend on the Prandtl number value [8], [9]. It is thus interesting to study the nature and thresholds of the instabilities of the thermocapillary flow in a full liquid bridge as a function of the Prandtl number. In that case, a 2D study [5] has shown an important variation of the thresholds with Pr.

The considered model consists of a vertical cylindrical liquid bridge, between two isothermal parallel concentric rigid disks, presenting a non-deformable free surface. This surface is submitted to a steady heating flux symmetrical about the horizontal mid-plane. The parameters of the model are the Prandtl number, the Marangoni number (Ma) which characterises the thermal convective regime and the aspect ratio $A = H/2R$ fixed here to 1. Gravity is absent. The capillary convective flow is governed by the Navier-Stokes and energy equations associated to boundary conditions which include the source of the flow. The mathematical system is solved with a spectral collocation code using a projection-diffusion method [1] in order to uncouple the pressure and velocity fields. The steady flows are calculated with a Newton method, the first unstable eigenmodes using an Arnoldi method [4]. These tools, in addition to direct numerical simulation, are necessary to observe transitions related to the mid-plane symmetry breaking of the 2D flow [3], due to the low values of the growth rates of the instabilities. The sensitivity of the solutions to the treatment of a vorticity singularity at the junction free surface/solid boundaries was studied in [6]. An first analysis of the most sensitive regions of the flow to local thermal perturbations with the adjoint technique has been initiated [2].

In the present contribution, we study the perturbation of the 2-D axisymmetric steady state through azimuthal modes as a function of the Prandtl and Marangoni number values. We will show that the critical Marangoni values are lower for 3D than for 2D perturbations for all Prandtl numbers but the azimutal Fourier modes, the bifurcation types and the threshold Ma_c values highly depend on the Prandtl number.

References

[1] A. Batoul, H. Khallouf, G. Labrosse, "Une méthode de résolution directe (pseudo-spectrale) du problème de Stokes 2D/3D instationnaire. Application à la cavité entrainée carrée", *C. R. Acad. Sci. Paris*, **319**, Série II, 1994.

[2] O. Bouizi, C. Dang Vu-Delcarte, "Localisation des zones sensibles aux perturbations en zone flottante par la méthode de l'adjoint", *Congrès français de thermique, SFT 2003*, Grenoble, 3-6 juin 2003.

[3] E. Chénier, C. Delcarte, G. Labrosse, "Solutions multiples thermocapillaires en zone flottante à gravité nulle", *EUR. Phys. Jour. AP*, **2**, 1998.

[4] E. Chénier, C. Delcarte, G. Labrosse, "Stability of the axisymmetric buoyant-capillary flows in a laterally heated liquid bridge", *Phys. Fluids*, **11**, 3, 1999.

[5] G. Kasperski, A. Batoul, G. Labrosse, "Up to unsteadiness of axisymmetric thermocapillary flows in a laterally heated liquid bridge ", *Phys. Fluids*, **12**, 1, 2000.

[6] E. Chénier, C. Delcarte, G. Kasperski, G. Labrosse, "Sensitivity of the liquid bridge hydrodynamic stability to the treatment of the contact free surface / solid boundaries", *Phys. Fluids*, **14**, 9, 2002.

[7] A.Cröll, Th. Kaiser, M. Schwizer, A.N. Danilewsky, S. Lauer, A. Tegetmeier, K.W. Benz, "Floating-zone and floating-solution-zone growth of GaSb under microgravity", *J. Crystal Growth*, **191**, 1998.

[8] L. Carotenuto, D. Castagnolo, C. Albanese, R. Monti, "Instability of thermocapillary convection in liquid bridges",*Phys. Fluids*, **10**, 3, 1998.

[9] M. Levenstam, G. Amberg, C. Winkler, "Instabilities of thermocapillary convection in a half-zone at intermediate Prandtl numbers", *Phys. Fluids*, **13**, 4, 2001.