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FINAL REPORT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MATERIALS-PROCESSING-IN-SPACE PROGRAM

"Thermocapillary Flows and Their Stability: Effects of Surface Layers and Contamination"

from

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PROGRESS REPORT

The research concerns the theoretical analysis of the fluid mechanics and heat transfer of motions driven by surface-tension gradients (Marangoni convection). The object of the work is to obtain an understanding of the convection accompanying the process of growing high-quality single crystals from the melt in a μ-g environment. The geometries considered in this work include two-dimensional liquid filled slots and axisymmetric float-zone configurations.

The following models were studied:

STEADY MARANGONI FLOWS

1. When a slot is differentially heated so as to impose a temperature gradient along the liquid-gas interface, a steady Marangoni flow can be induced. We have obtained approximate solutions for the flow field, temperature distribution and surface deflection as functions of the Marangoni number M, the Prandtl number P and the capillary number C for long, thin slots when the liquid-gas interface is clean.

   reference: Sen and Davis (1982)

2. When the liquid-gas interface of the slot from #1 is contaminated with surface active material, the steady Marangoni flow is retarded. We have obtained such steady flows for cases in which the contaminant material is a non-condensed monolayer and determined the dependence of the flow on the surface Peclet number and the Gibbs surface elasticity.

   reference: Homsy and Meiburg (1984).

3. In both planar cases #1 and #2, we obtain flows for thin slots. These flows have only small or moderate values of the Marangoni number so that convective transport of heat is small compared to that due to conduction. Here we examine the case of clean interfaces when the Marangoni number is large. We use a simplified geometry and obtain estimates for the Nusselt number, the measure of the transport of heat due to convection. For large Prandtl number, $N \sim M^{2/7}$.

   reference: Cowley and Davis (1984)

4. When the liquid forms a cylindrical float zone and axial temperature gradients are imposed, steady Marangoni convection can be induced. We have extended the work of Sen and Davis (1982) to this new geometry and obtained the flow and heat transfer possible when significant liquid-gas interface deflection is possible.

   reference: Xu and Davis (1983)

STABILITY OF MARANGONI FLOWS

5. We have examined the steady Marangoni flows of #1 above and analyzed the stability characteristics of these. We find that if the Prandtl number P is small that the instability is oscillatory in time and is associated with the interaction of liquid-gas interface deflection with the underlying shear flow. Thus, even though the thermocapillary effect drives the steady motion, it has little effect on the instability characteristics; the instability is a mechanical one. If P is large then the instability is either oscillatory in time or a steady cellular one. In either case the instability is associated with the thermal

field and depends little on the deflection of the liquid-gas interface; the instability is a thermal one.

references: Smith and Davis (1982), Smith and Davis (1983a), Smith and Davis (1983b)

6. We have examined the convective instabilities in float-zone geometry to obtain the analog of the results of #5. Comparisons are in qualitative agreement with the experiments of Schwabe et al. in Germany but buoyancy effects in the experiments are seemingly large.

reference: Xu and Davis (1984a)

7. We have examined the mechanical instabilities in float-zone geometry to obtain the analog of the results of #5. Here both Smith and Davis (1983b) - type and capillary instabilities are present.

reference: Xu and Davis (1984b)

8. We have examined the effects of buoyancy on float-zone motions induced by Marangoni effects in order to better compare our theories with the experiments of Schwabe et al. The steady Marangoni convection has been calculated, and most of the stability characteristics have been obtained.

reference: Xu and Davis (1984c)

SUMMARY: Steady Marangoni flows have been described. Several new thermocapillary instabilities have been uncovered. The tendency of float-zone melts to become oscillatory is strongly dependent on the Prandtl number P of the melt. Small P materials behave vastly differently than do large P materials. The present work sets out a large body of new fluid-dynamical effects of direct use in understanding the behavior of the flows in float zones.

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