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YEAR TWO ANNUAL 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 during the past year:

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: Meiburg and Homsy (1982).

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 (1982)

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 (1982a).

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. We have made good comparisons with the experiments of Scharmann et al. in Germany. We feel now that we can completely characterize instabilities in Marangoni layers.

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

6. We are in the process of studying the instabilities in a float-zone geometry to obtain the analog of the results of #5.

reference: Xu and Davis (1982b)

SUMMARY

The work is proceeding on schedule. We are excited by the breadth and depth of the results obtained so far.

WORK TO BE APPROACHED IN YEAR THREE

1. The work on the influence of contamination, #2 above, will be completed and extended to more complex monolayer models.

2. The work on high Marangoni number convection, #3 above, will be completed. We shall try to extend this analysis to axisymmetric float-zone geometries.

3. The instabilities of Marangoni flows in float-zone geometries, #6 above, is under way and will be completed.

4. We wish to examine the effect of instabilities on the heat transport within a melt. Hence, we shall examine the nonlinear instability theory

of #5 and #6 above. This would give us estimates of the augmentation of heat transport due to instabilities.

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