Effect of Marangoni Convection Generated by Voids on Segregation during Low-G and 1-G Solidification

M. Kassemi[1], A. Fripp[2], N. Rashidnia[1], and H. de Groh[3]

[1] NCMR, NASA Lewis Research Center, Cleveland, Ohio
[2] NASA Langley Research Center, Hampton, Virginia
[3] NASA Lewis Research Center, Cleveland, Ohio

This work is concerned with mixing caused by Marangoni convection generated by voids and bubbles in the melt during both 1-g and low-g solidification experiments. The objective of the research is to perform a detailed and comprehensive combined numerical-experimental study of Marangoni convection caused by voids during the solidification process and to show how it can affect segregation and growth conditions by modifying the flow, temperature, and species concentration fields in the melt.

Solidification experiments, especially microgravity solidification experiments, are often hampered by the evolution of unwanted voids or bubbles in the melt. Although these voids and/or bubbles are highly undesirable, we have currently no effective means of preventing their formation or eliminating their adverse effects, particularly during low-g experiments. Marangoni Convection caused by these voids can drastically change the transport processes in the melt and, therefore, introduce enormous difficulties in interpreting the results of the space investigations. Recent microgravity experiments by Matthiesen (Study of Dopant Segregation Behavior During the Growth of GaAs in Microgravity), Andrews (Coupled Growth in Aluminum-Indium Hyper Monotectics), and Fripp (Lead-Tin-Telluride, Growth in a Low-G Environment) are all good examples of how the presence of voids and bubbles affect the outcome of costly space experiments and significantly increase the level of difficulty in interpreting their results.

While Marangoni convection generated by bubbles and voids in the melt can lead to rapid mixing that would negate the benefits of microgravity processing, it could be exploited in some terrestrial processing to ensure effective communication between a melt/solid interface and a gas phase stoichiometry control zone. Thus, we hope that this study will not only aid us in interpreting the results of microgravity solidification experiments hampered by voids and bubbles, but guide us in devising possible means of minimizing the adverse effects of Marangoni convection in future space experiments or exploiting its beneficial mixing features in ground-based solidification.

In order to quantify the extent of the Marangoni convection generated by voids in typical solidification experiments, a comprehensive experimental numerical study is adopted with five major components:

1. Solidification experiments using acetone-doped succinonitrile (SCN), a transparent model material which allows direct visualization of temperature and flow fields.
2. Post-growth characterization of the solid to determine levels of segregation.
3. Controlled flow and temperature visualization experiments with different grades of silicon oil to determine the Pr number effect which is needed for extrapolating the results of the SCN experiment to growth of low Pr number (high conductivity) materials.
4. Development of a comprehensive numerical model, simulation of the entire process for 1-g and low-g conditions, and verification of the model against the results of the ground-based experiments.

5. Use of the verified numerical model as an effective tool to simulate previous microgravity solidification experiments which involved different alloy materials and growth conditions.

Currently, a collaborative effort with Dr. Padetha Tin (OAI) is underway to measure the surface tension and kinematic viscosity of SCN with respect to temperature. A non-invasive technique is employed to relate the light scattered by the thermally excited surface capillary waves (ripplons) to surface tension and viscosity of the liquid melt. A spectrometer measures the power spectrum of the scattered waves using a laser heterodyne technique. The power spectra carries all the relevant physical information which can be related to surface tension and kinematic viscosity of the liquid through dispersion relations derived from the Navier Stokes equations. In the near future, this work will be extended to include measurement of the melt surface tension as a function of dopant (acetone) concentration. Preliminary effort has also started in developing a finite element model for the process. The numerical model will initially be used to design the SCN solidification experiments and the desired the parametric matrix for the test runs. At a later stage, an energy-based phase field method will be used to model the vapor bubble and its motion in the melt region. The phase field approach together with the Navier Stokes equations provide a continuum surface tension approach which can be used to model and study the vapor-liquid interactions in the melt quite efficiently using a fixed finite element grid.