Exploiting the Temperature/Concentration Dependence of Magnetic Susceptibility to Control Convection in Fundamental Studies of Solidification Phenomena

James W. Evans, Chancellor's Professor
Dept. of Materials Science & Mineral Engineering
University of California at Berkeley
Berkeley, CA 94720
Phone: 510 642-3807
Fax: 510 642-9164
E-mail: evans@socretes.berkeley.edu

and

Dong Xu, Visiting Scholar
W. Kinzy Jones, Jr., Graduate Student, University of California at Berkeley
Frank R. Szofran, NASA Marshal Space Flight Center

The objective of the proposed investigation is to demonstrate by experiment (supplemented by mathematical modeling and physical property measurement) that the effects of buoyancy driven convection on solidification can be largely eliminated in ground-based experiments, and further reduced in flight, by application of a new technique which exploits the dependence of magnetic susceptibility on temperature or composition.

The research is related to NASA investigations (both past and ongoing) into the great influence that convection can have on the microstructure and properties of materials (the majority) that are produced by solidification. Elimination of this convection has both scientific and technological consequences. Our knowledge of diffusive phenomena in solidification, phenomena normally obscured by the dominant convection, is enhanced if we can study solidification in quiescent liquids. Hitherto, the method of choice for eliminating convection has been experimentation in low Earth orbit. However, even there, residual convection is present due to residual accelerations (drag on the spacecraft or displacement of the experiment from the mass center of the craft) or transients in the gravitational field. There is therefore a need for further reducing buoyancy driven flow in flight and for allowing the simulation of microgravity in ground-based experiments.

In the first half of this decade it has been shown (in investigations concerned with heat transfer, rather than solidification) that convection can be halted for many liquids by exploiting the variation of the magnetic susceptibility of the liquid. [It is emphasized that this approach is fundamentally different from the magnetic damping that has been well studied in the past.] The convection is halted by a body force which is -susceptibility x grad(B^2)/permeability of free space, where B is the magnetic flux density. In a magnetic field of the right size (and reasonable uniformity) buoyancy effects arising from density differences in a gravitational field are exactly canceled by an opposing buoyancy effect arising from susceptibility differences in the grad(B^2) field. To exploit this effect in experiments on the solidification of model alloys, it is best to have data on the concentration or temperature dependence of the susceptibility. Such experiments are planned for the High Magnetic Field Solidification Facility (HMFSF) at the NASA Marshall Space Flight Center and will entail following the convection during solidification of model alloys using particle image velocimetry (PIV). In the planned experiment, the pool of model alloy will be placed in a chamber at the mouth of the superconducting magnet. A temperature gradient will be maintained across the pool by circulating water from two precision water baths through opposing walls of the chamber; in this way both static (arrested solidification front) and dynamic (moving front) experiments will be possible. The pool will be observed (the model alloy being transparent) from

above by a CCD camera and the velocities of tracer particle measured by PIV to yield quantitative information on the flow.

Halting convection in this way will permit the examination of the role of several diffusive phenomena (e.g., the Soret effect) in solidification. It is anticipated that the investigation will eventually lead to flight experiments in which microgravity can be further reduced and, perhaps, the effects of g-jitter controlled, using orthogonal solenoids (which need not be superconducting magnets to oppose the weak effects of microgravity) placed around an experiment.

Work in the first few months of this investigation has entailed measurement of the susceptibility of candidate model alloys as a function of composition and temperature. Additionally, computations have been carried out of the magnetic field, grad(B^2) and necessary field strength for halting convection in the HMFSF.