Flow and Shape Instabilities of Freezing in a Lid Cooled Cavity

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ABSTRACT

Heat and mass transfer accompanied by a change of phase (solidification or melting) are receiving increasing attention, mainly because of the broad range of technological applications and applied research fields where these phenomena play a prevailing role. The problem is rather complex. Several time and length scales spanning many orders of magnitude are simultaneously responsible for setting the flow and thermal fields for moving boundary conditions at the interface between liquid and solid. The aim of this study is to examine flow regimes that arise in the vertical, Bridgman like configuration, one of the simplest ways of growing crystals. For this purpose the onset of thermal convection of water in a lid cooled cube shaped cavity was studied experimentally and numerically.

The experiments were performed in $38 \times 38 \times 38$mm plexiglas and glass boxes. The metal lid was instantaneously cooled to a temperature of -10^oC, whereas the other five non-adiabatic walls of the cavity allowed the entry of heat from an external bath. Its temperature was varied from 5^oC to 20^oC. The corresponding values of Rayleigh number were in the range from $Ra = 7.7 \times 10^5$ to $Ra = 3.1 \times 10^6$. The temperature and velocity fields in the cavity were measured by means of liquid crystals suspended as small tracer particles in the liquid [1]. After onset of convection various cold plumes falling down along side walls were observed. Before the final steady, symmetrical state was reached, the flow changed its pattern and direction through several complicated configurations. The flow symmetry was usually disturbed by small imperfections of the cavity and fluctuations of the initial field conditions. When a solidification front started advancing into a region of supercooled liquid, the initially planar ice surface was subject to instabilities which led to complex modes of growth. The effect of initial and boundary conditions on the flow and ice structure was studied. It was found that originating the freezing process from the fully developed convection flow reduced the flow instabilities and a regular, semi-steady growth of the ice crystal was achieved.

The experimental data (interface position, temperature and velocity fields) were compared with a numerical model. A three-dimensional numerical code ICE3D [2] has been used. The Navier-Stokes and energy equations are solved using a finite difference method for the phase change boundary fitted computational grid. The presence of the initial flow and ice shape instabilities were also found when performing the numerical simulation. They were easily initiated by the "numerical noise" of the initial conditions. The generation of solutions describing the stable flow pattern and symmetrical growth of the solidification front was possible by setting the appropriate initial and boundary conditions found in the experiment.

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[2] Yeoh, G.H., Natural convection in a solidifying liquid, Ph.D. thesis, University of New South Wales, Kensington, Australia, 1993.