2. ISUD
2nd International Symposium on Ultrasonic Doppler Methods
for Fluid Mechanics and Fluid Engineering
September 20-22, 1999
Paul Scherrer Insitut, 5252 Villigen PSI, Switzerland

Sidewall Convection in Liquid Gallium

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Introduction

Side wall convection in liquid metals is an important problem in the semiconductor crystal growing process known as the Bridgman technique. In this a crucible of molten material is slowly drawn from a furnace and solidification takes place as the container is exposed and cools.

This technique is used in the growth of high-quality materials for optoelectronic applications, for example. The industrial process may involve dendrite growth and the distribution of dopants and is thus a complicated problem. However, insights can be gained from studying the basic fluid dynamics that result from the differential heating of the sample since other processes are strongly influenced by the induced motion. For small temperature differences, the convection is steady and primarily consists of a large, single circulation. However, the bulk flow in a confined cavity evolves considerably for larger values of the driving force, as the interaction between the different regions of flow becomes significant. Thus, the mechanisms underlying the transitions to time-dependent and eventually turbulent flow are often complex. In crystal growth processes the temperature gradient between the melt and the solid gives rise to buoyancy driven convection. In most practical situations the motion so induced is found to be highly disordered or even turbulent. It is known that these flows can produce irregular distributions of dopant called striations in the host material and this inhomogeneity is undesirable if one wants to grow good quality semiconductor crystals. Hence there is considerable interest in methods of suppressing or controlling fluid convection.

One method of controlling the convection is to apply an external magnetic field. This induces an electromotive field which can be non--uniform in regions in the melt. Hence electrical currents can flow, and these interact with the applied magnetic field to damp the convective motion. These effects can be calculated explicitly for simple geometries but laboratory and practical flows are extremely complicated and require numerical computations. It is the aim of the present study to investigate the fundamental magnetohydrodynamic interactions in a simplified crystal growth geometry using a combined experimental and numerical approach. By doing this we hope to gain insight into the basic fluid mechanical processes and thereby provide a platform on which to build an understanding of more practical flows.

An investigation of the effects of a magnetic field

We will first discuss the results of an experimental and numerical study of the effects of a steady magnetic field on side wall convection in molten gallium. The magnetic field is applied in a direction which is orthogonal to the main flow. The convection is reduced by the magnetic field and good agreement is found for the scaling of this effect with the relevant parameters. Moreover, qualitatively similar changes in the structure of the bulk of the flow are observed in the experiment and the numerical simulations. In particular, the flow is restricted to two dimensions by the magnetic field, but it remains different to that found in two-dimensional free convection calculations. We also show that oscillations found at even greater temperature gradients can be suppressed by the magnetic field.

An investigation of structure of the flow field

Next we will report the results of an experimental and numerical investigation of the steady flow of molten gallium in a differentially heated rectangular enclosure. Excellent agreement is found between the experimental results and those from a full three-dimensional numerical simulation based on a Boussinesq model. Qualitative differences are uncovered between these new findings and published results obtained from analytical and two-dimensional models. Detailed features of the flow are examined and the significance of cross-flows in the centre of the cavity is revealed. Specifically, we show that the transition to time-dependent flow will be different in two and three-dimensional models.

Secondary flows are found to be important and these show a strong dependence on the Prandtl number emphasising the role of this parameter in the problem. Some discrepancies are found between the results from the numerical centro-symmetric model and the experiment which arise from unavoidable external influences.

Juel, A., Mullin, T. Ben Hadid, H. & Henry, D. 1999 Magnetohydrodynamic convection in molten gallium. J. Fluid Mech., 378, 119-144.

Juel, A., Mullin, T. Ben Hadid, H. & Henry, D. 1999 Three-dimensional free convection in molten gallium. J. Fluid Mech.(Submitted)