AHP SETUP FOR LOW LAMINAR MELT FLOW STUDY IN CRYSTAL GROWTH

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Summary For verification of numeric methods and development of experimental benchmarks for 2D and 3D models of heat and mass transfer in crystal growth, the experimental AHP setup based on a novel AHP crystal growth method is designed to conduct experiments with $NaNO_3$ and ice. It is equipped with PIV and PVT visualizations systems to provide finding of field of flow velocity and temperature distribution in the fluid. Preliminary investigations have proved the possibility to suppress natural convection and to create low melt flow similar to micro gravity conditions and shown good coincidence of calculated data on mass transfer with those observed in the experiment.

INTRODUCTION

Solid-liquid phase-change phenomena are present in a large number of industrial applications and natural processes. Numerical modelling of such strongly non-linear, moving boundary, thermal and fluid flow problems is not a trivial task. In the case of solidification, the planar interface appears to be unstable depending on environment conditions, creating different structures, such as cells or dendrites. These local mechanisms have drastic consequences at a larger scale and convective motion in the interdendritic melt is a primary cause for a macrosegregation that is the variation in composition of a solidified alloy for instance. In the microgravity environment, despite the absence of natural convection, problems arising from the effects of Marangoni convection or g-jitter effects seriously damped initial enthusiasm on using space labs for crystal growth.

Computer simulation has a major relevance as a tool of analysis of the experimental studies or for the design of engineering hardware. In order to assess a satisfactory level of confidence of the simulation tools, both the model and the procedure have to be tested through properly designed validation experiments, reproducing the basic features of the simulated phenomena. Therefore, experimental benchmarks for code validation have gained a special attention in the recent years.

In the prevailing growth methods, when a strong forced or thermocapillary convection takes place, a complex flow unstable by its nature is formed. Under such conditions, it is extremely difficult to realize quantitative correlation between experimental and calculated data. In this connection, special interest presents solidification from a thin melt layer [1,2] when low laminar flows are initiated. Employing modern visualization tools, which provide a way for thermometric and velocimetry measurements, and expanding a number of model liquids, it is possible to carry out researches in heat and mass transfer during solidification within a wide range of determining parameters.

SETUP AND EXPERIMENTAL TECHNIQUE

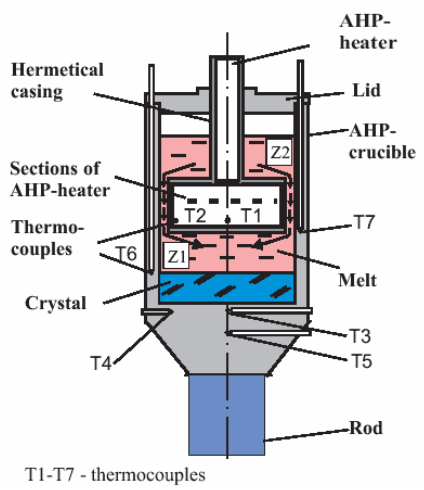

Figure 1. Schematics of AHP crystal growth

A novel AHP method of crystal growth under conditions of Axial Heat flux close to Phase interface characterized by an additional heater placed inside in the melt close to the solid-liquid interface was previously proposed [2]. Functioning as a baffle [1], a submerged heater divides the melt into two zones Z1 and Z2 (Fig. 1). The zone above the AHP-heater, Z2, serves for feeding the solidification zone Z1 with the melt (under the heater). Processes in these zones do not affect each other. In zone Z1, the natural convection of the melt is suppressed and a low melt flow, arising due to movement of the crystal with the crucible relatively to the AHP-heater, is laminar and steady-state. In case when thermocouples are installed along all boundary surfaces, it is possible to control during the growth cycle the basic technological parameters: position and shape of the solid-liquid interface, actual growth rate of a crystal, and temperature gradient at the solidification front.

With the aim to observe the behavior of low AHP flow, an experimental AHP setup for visualization of $NaNO_3$ crystal growth [3], employing 20 μm particles of aluminum powder as tracers, was designed. The fragment of crystallizer is presented in Fig. 2. The $NaNO_3$ charge was completely molten with the background heater, the AHP-heater was submerged into the melt, and thermal conditions were established under which a part of the melt was solidified. In this case, the solid-liquid interface was formed at a certain distance within 5-20 mm from the AHP-heater bottom. Varying power of the background and AHP-heater sections, the planar shape of the phase interface was established. The crucible was pulled down, while the AHP-heater was stationary.

Another type of crystallizer is designed for visualization of fields of velocities and temperature distribution in the liquid, as well as for investigation of faceted growth effect on heat and mass transfer and origin of morphological instability in ice growth.

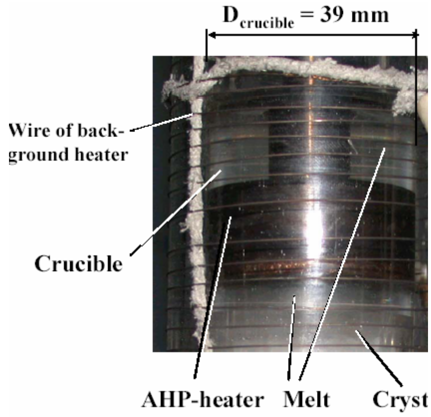

Figure 2. $NaNO_3$ solidification in AHP method

Particle image velocimetry (PIV) as well as particle image thermometry (PIT) are used as a quantitative determination of the velocity and temperature map in a convective flow field. PIT is based on the property of certain thermochromic liquid crystals (TLCs), with diameter of 10-100 µm, to reflect light of various colors depending on their temperatures and the observation angle. In PIV, flow is illuminated by a xenon flash or a halogen lamp and observed at 90 ^{0} by a high-resolution 3-CCD color camera (see Fig. 3). The evolution methods and their software were successfully developed in house [4]. Being applied to ice solidification, the flow images are used to evaluate the shape and location of the phase front. These measurements are performed using image analysis software. As for the solidification front, the edge detection, supported by manual intervention, appeared to be the most efficient way to find the interfacial profiles [5].

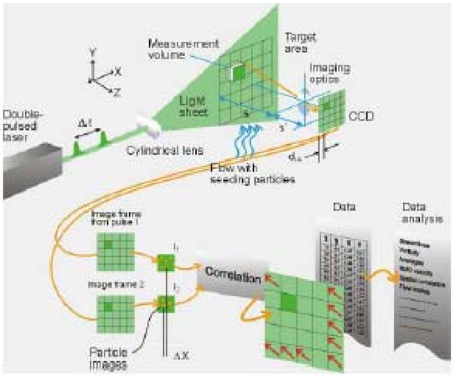

Figure 3. Schematics of visualization system

RESULTS

Setup examination was carried out in growth of $NaNO_3$ crystals at 7 mm/h rate. The axial temperature gradient in the melt was 20-40 K/cm and the radial temperature gradient was 1.2-1.3 K/cm. The solid-liquid interface was planar in all experiments. Depending on thickness of the set melt layer, the Rayleigh number did not exceed 30000. The laminar character of convection, varied from pronounced natural one with two vortexes, located close to the solid-liquid interface, up to, practically, pure forced convection [6], was well observed. Performed numerical computations have shown a good quantitative coincidence. It has been found that the natural convection is completely suppressed (Fig. 4) at the melt layer of 2 mm (Ra_{radial}=900), and heat and mass transfer becomes similar to that under microgravity conditions.

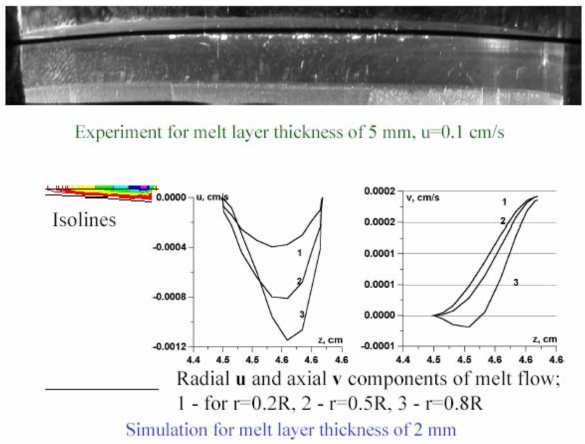

Figure 4. Forced low melt flow during $NaNO_3$ solidification

CONCLUSIONS

It has been shown that crystal growth by the AHP method is characterized by low laminar flows. This allows obtaining experimental benchmarks and testing of 2D and 3D codes for simulation of convection under conditions of phase change. Due to selection of the melt layer, it is possible to create conditions at which forced convection plays a dominant role. Such flows can be considered as benchmark ones and employed as tools for studying the effect of convection nature on growth of a crystal and formation of its structure. The research was sponsored by INTAS-99-01814 and by CRDF RE1-2480.

References

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