TEMPERATURE AND FLOW VISUALIZATION IN A SIMULATION OF THE CZOCHRALSKI PROCESS USING TLCs

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There is no doubt today that thermal and thermocapillary convection play the dominant role in impulse, heat and mass transfer in the Czochralski crystal growth method. Because of the complexity of the problems, measurements in one point of the volume are not sufficient to illuminate the flow topography and to compare the experimental results with the real or numerically simulated ones. Therefore it is of great interest to measure the temperatures and velocities in the whole field in order to qualitatively analyze the thermally driven convections. A new experimental Particle Image Thermometry (PIT) method based on computer-aided colour analysis of the Temperature-sensitive Liquid Crystals (TLCs), which is reported here, enables to determine the temperature and velocity fields simultaneously.

INTRODUCTION

In the Czochralski crystal growth method, a polycrystalline structure is melted in the crucible at a temperature that is a little higher than the melting point. A germ bud is then brought on to the surface of the melt. The melt solidifies on the surface of the germ bud and creates a monocrystalline structure. The growth of the monocrystal into the melt is prevented by pulling the monocrystal slowly and uniformly, at 0.1 to 100 mm/h, and rotating it at 1 to 100 rpm. A regular crystal rod is thus built up and new layers are attached to it. To increase the quality of the crystal and to optimise the process, it is necessary to identify and investigate the types of convection which occur in the operating parameters range and the conditions that the transient convection appears.

OPTICAL FLOW MEASUREMENT SYSTEMS

The aim of the measurement systems associated with PIT is the quantitative determination of the temperature field in a convective flow. PIT is based on the property of certain liquid crystals with a diameter of 10 – 100 μm to reflect light in different colours, depending on their temperature and the observation angles. This property was used in the Czochralski method simulation together with Particle Image Velocimetry (PIV). In PIT, the light sheet from the white light source was recorded with a digital camera. The light source for a 1.5 mm thin light sheet was a halogen lamp. The evaluation methods and their software were successfully developed in house. The same TLCs were used in PIV as tracers to determine the flow velocity. Figure 1 shows the layout of the optical flow measurement systems in the experimental set up.

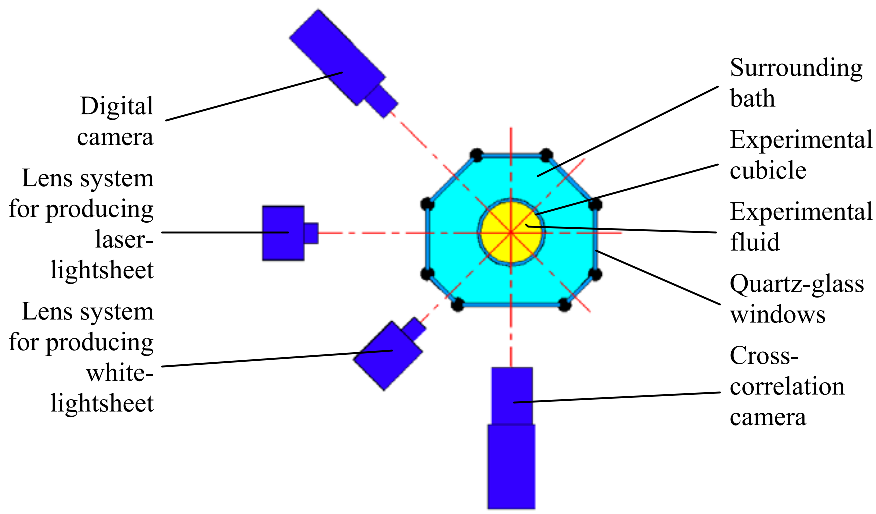


Figure 1: Lightsheet method system in the experimental equipment

RESULTS

It appears that three kinds of convection in the liquid were involved in the process at hand:
1) Marangoni convection – thermocapillary flow, due to the liquid–air interface stress; 2) Thermal convection, due to density variation with temperature in the fluid layers, and 3) Forced convection, due to the rotation.

The effects of changing the aspect ratio, the Prandtl (Pr), Marangoni (Ma) or the rotatory Froude (Fr) Numbers on the flow topography could be identified by changing the thermal and kinetic boundary conditions and determining the temperature and velocity fields.

Figure 2 shows the effect of the Pr No on the temperature and velocity fields. In the case of a very large Pr No (Fig. 2A) the temperature field is quasi-symmetrical. The large Ma No suggests a strong boundary driven convection. It is also an indicator for entranced heat transfer with a decreasing Pr No and the consequently larger warm flow spread through the volume (Fig. 2D). In the case of a very large Pr No (Figs. 2B&2C), a strong Marangoni convection was build up and the velocity field was laminar and rotational-symmetrical. A swiftly, cold, downward flow (a so called jet) seemed to form in the middle of the cubicle and reinforced by the thermal convection. The flow was steady and stable with a stable topography. A reduction of the Pr No results in the destruction of the stability and flow symmetry (Figs. 2E&2F). A secondary temperature gradient was formed, which destroyed the stable density layers and a second convection roll was formed.

SUMMARY

The melt flow was laminar for all investigated values of the Pr, Ma and Re Nos. The temperature and velocity field are coupled. The convection flows determinates the heat transfer. Instability of the flow can be expected at small Pr No with an unstable devolution and a permanently changing flow topography. A growing Re No yielded the same result. It has yet to be determined whether this flow turns into some other mode and whether it leads to an oscillatory buoyancy driven flow.

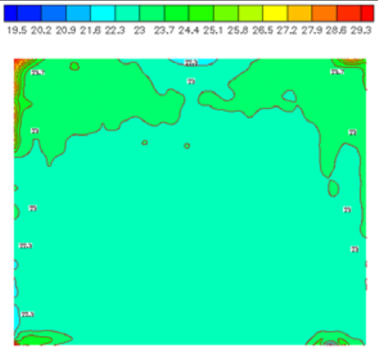
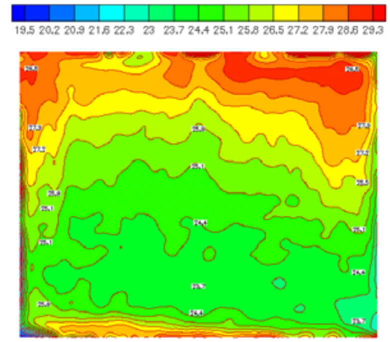
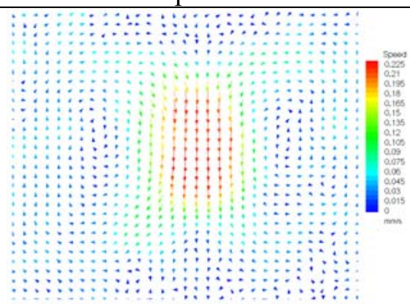
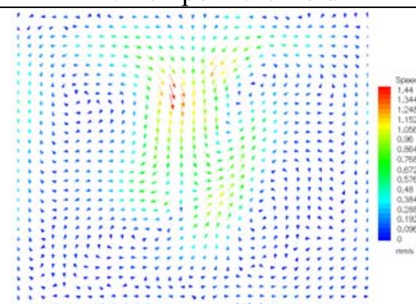
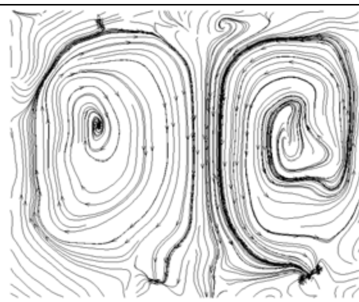
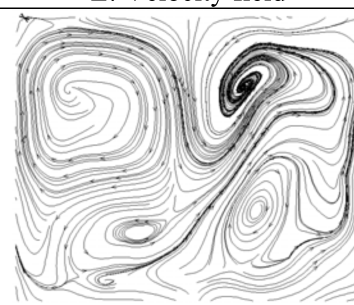
 A: Temperature field	 D: Temperature field
 B: Velocity field	 E: Velocity field
 C: Streamlines	 F: Streamlines
Ma = 590.9, Pr = 8226.8, Re = 0.07	Ma = 43020, Pr = 39.66, Re = 1841.43

Figure 2: Boundary conditions with the appendant temperature and velocity fields, streamlines and the dimensionless numbers

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