Experimental prediction of instabilities in Czochralski melt flow configuration

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ABSTRACT

This study is devoted to experimental measurements of primary and consequent bifurcations of flow driven by buoyancy, thermocapillarity (Marangoni convection) and rotation in Czochralski (CZ) configuration. Our primary efforts are focused on developing of an experimental facility for measurement of instabilities in a model of CZ melt flow with the main purpose of providing experimental data for validation of computational modelling for detecting the instability onset. The study is motivated by instabilities observed during growth of rare-earth scandates [2], whose melt Prandtl number is of the order of 10. The characteristic size of experimental setup is chosen large enough to keep the critical temperature differences around few degrees. This allows us to use distilled water and silicone oils as working liquids without accounting for their temperature-dependent physical properties in consequent computational modelling.

An experimental system that mimics CZ melt flow includes cylindrical glass crucible insulated by a double-glass shell with vacuum inside. Two thermal bathes with very accurate temperature control are used to set the temperatures of a copper crystal dummy, the crucible wall and the crucible bottom. The experimental setup allows one to vary the temperature difference between the cold crystal dummy and the hot crucible wall and the crystal dummy rotation rate in wide ranges. Special measures have been made to increase the accuracy of absolute temperature measurements by using in-situ calibration of the thermocouples. A very accurate data acquisition and signal conditioning system enables one to resolve absolute temperatures with precision better than 0.01^{o}C while temperature oscillations can be measured to within the amplitude of 0.005^{o}C. The advantage of the system is its ability to measure static instabilities such as symmetry breaking and not only onset of temperature fluctuations. The Mach-Zehnder interferometry was used along with the thermocouples measurements, so that the thermocouples measurements are cross verified by independent and nonintrusive observations.

Our recent experiments carried out using silicon oil (20 cSt) as a working liquid revealed so-called “cold plumes" instability appearing at about $\Delta T_{cr} = 2.5^oC$. This instability sets in with a time period of about 25 sec. The dependence of ΔT_{cr} on the crystal dummy rotation is being studied and will be reported at the conference along with the comparison of experimental and numerical results. Future work will be expanded to study temperature instabilities with different silicon oils as working fluids and with rotation of crystal dummy in wide range. Our goal is to validate experimentally a series of numerical predictions indicating on a strong destabilization of high-Prandtl-number CZ flow by crystal rotation [2,3].

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