THERMOELECTRICALLY DRIVEN MHD FLOW FIELD IN UNDERCOOLED CRYSTAL GROWTH

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This paper investigates the complex fluid structures that may form during the undercooled growth of a single equiaxed dendrite placed in an externally applied magnetic field. Due to variations in surface temperature along the solidification front, thermoelectric currents form, which interacting with an external magnetic field result in a Lorentz force that drives microscopic fluid flow. The phenomenon was named Thermoelectric Magnetohydrodynamics (TEMHD) by Shercliff . Depending on the alloy's thermoelectric properties TEMHD can be a dominant mechanism in interdendritic spaces and consequently have a significant impact on crystal morphology . Such a situation arises during electromagnetic levitation experiments, where the application of an external DC magnetic field is commonly used to dampen macroscopic flow [1].

A fully coupled 3-dimensional time-dependent numerical model incorporating solidification, thermoelectrics and fluid flow has been developed to analyzed the evolution of both the solidification front and the fluid structure for various orientations of the magnetic field. The results of the simulations have been presented in previous publications [2].

The situation is complex both physically and computationally and difficult to interpret. By topographically representing the dendrite as a sphere and mapping the surface energy on its surface, a closed analytic solution can be obtained. Furthermore, in a low magnetic field limit, the solution becomes linear. Due to the cubic symmetry of the surface energy and the inter-changeability of the Cartesian axes, it is only necessary to solve for a single orientation of the magnetic field. Combined with linear superposition, the fluid structure can determined for any orientation of the magnetic field.

A comparison to the numerical simulations for a small crystal at an early growth stage (fig.1), gives good agreement for both the direction and magnitude of fluid flow, which develops a complex vortical structure.

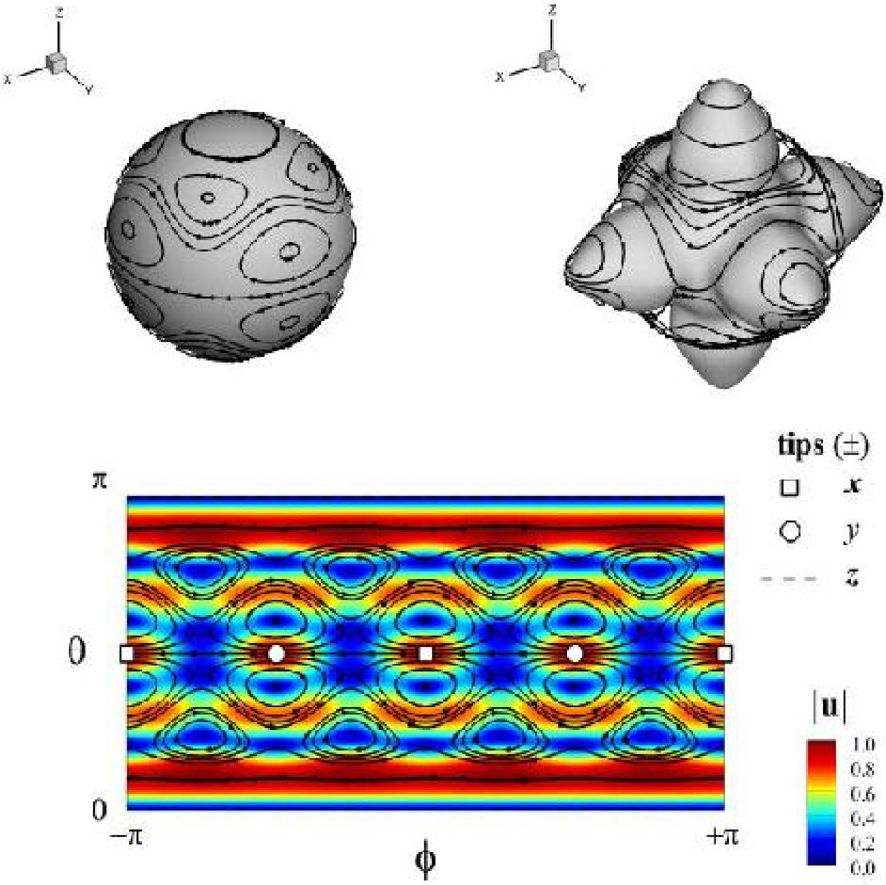

Figure 1: Fluid flow for a z-orientated magnetic field. Top left: analytic solution. Top right: numerical solution. Bottom: Mercator projection.

References

[1] H. Kotabate, H. Fukuyama, T. Tsukada, S. Awaji, Measurement Science and technology, vol. 1, no.2, 2009.
[2] A. Kao and K. Pericleous, Magnetohydrodynamics, vol. 48, no. 2, 361-370 (2012).