ANISOTROPY OF FLOW AND TRANSITION BETWEEN MIXING REGIMES IN STRATIFIED EM FORCE GENERATED FLOW

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As fossil energy resources are getting exhausted, demand for alternative energy sources is growing. In 2011 in Germany the renewable energy part was 12.5%, which is almost doubled since 2005 [1]. Photovoltaic solar energy still has small fraction of the total power production – only around 2% - but it is still growing. Directional solidification (DS) is widely used for the production of photovoltaic materials for convenient and material-loss effective wafer production. The production process of the polycrystalline material influences the quality of the wafers significantly and for this reason design of DS furnaces has to be proceeded with care. One of aspects influencing the successful material production is the melt flow in the crucible during solidification stage [2]. This work is devoted to numerical and experimental investigation of the Lorentz force generated turbulent melt motion at moderate Reynolds numbers (2000-10000) in a square crucible where vertical temperature gradient is present and causing stratification of flow.

Experimental results were obtained using physical model, which consisted of square crucible, placed on aluminium plate with constant temperature and covered by heater-lid, which allowed obtaining vertical temperature gradient in melt. Wood's alloy (50% Bi, 25% Pb, 12.5% Sn, 12.5% Cd, melting temperature 72°C) was used as working liquid. Experimental set-up allows measuring velocity field in the crucible using Ultrasound Doppler Velocimetry (UDV) technique and temperature dynamics using thermocouples. Results show that there is steep transition from 3D flow to quasi two-dimensional flow near critical Richardson number Ri_{CR}~5..10. As Richardson number increases any vertical motion of fluid becomes more damped by buoyancy forces and 2D turbulence takes place. However, 2D turbulence appears at reasonably higher Richardson numbers than transition to 2D flow, $Ri \sim 10^3$, which is not possible to realize in this experimental set-up. Stratified flow is well known to possess wave-like flow character in high-Ri region, where so-called weak mixing regime with high turbulent Prandtl number takes place [3].

Numerically the melt flow in described system was investigated using Large Eddy Simulation (LES) approach. Simplified thermal boundary conditions were used – constant temperature at bottom, adiabatic walls and constant temperature or convective type boundary condition at top. OpenFOAM code was used for fluid dynamics calculations and GetDP as electromagnetic solver. LES results match well with UDV measurements and also show transition between different flow regimes at Ri_{CR}. Another issue resolved in LES is that anisotropy of flow increases with Richardson number. To quantify this effect anisotropy coefficient was used. LES results also show that in such square crucible plane of symmetry of flow field can differ from plane of symmetry of EM forces.

References

[1] Bohme, D.: Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2011. http://www.erneuerbare-energien.de.
[2] Reimann, C. et al.: Journal of Crystal Growth, 2010, vol. 312. p. 878.
[3] Zilintikevich, S.S. et al.: Q. J. R. Meteorol. Soc. 134 (2008) 793–799.
[4] Smith, W.D. et al.: Phys. Fluids, 2000, vol. 12, no. 6. p. 1343-1362.