# Modelling of Turbulent Melt Flow in CZ Silicon Single Crystal Growth System Using OpenFOAM

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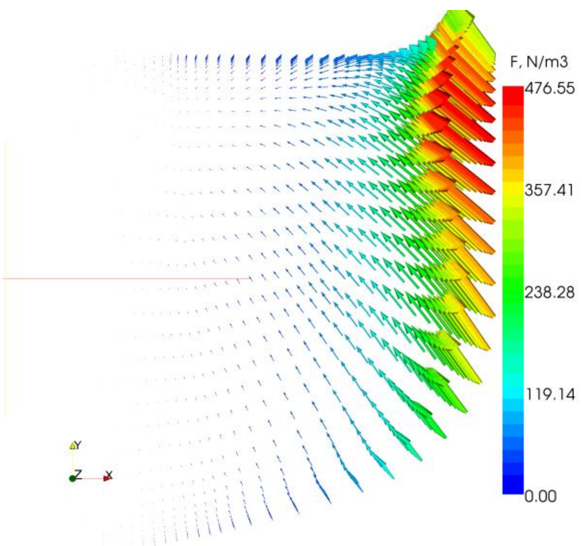
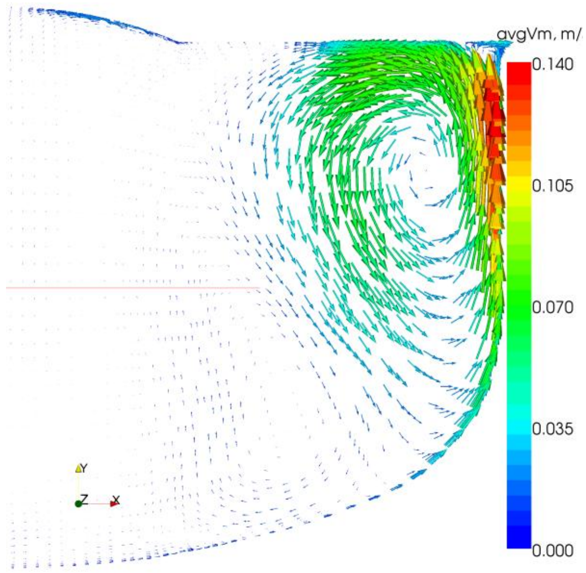
Mathematical modelling of the melt flow and heat transfer for industrial Czochralski (CZ) Si single crystal growth systems has become an important instrument for optimization of the crystal growth processes. Open-source program package *OpenFOAM* is a set of HD and heat transfer solvers and pre- and post-processing tools that after proper adaptation can be used to model almost every aspect of the industrial Si crystal growth. *OpenFOAM* is extremely flexible and allows the user to create new tools, solvers, and boundary conditions to suit their needs. It comes also with a large set of built-in turbulence models and provides the means for parallelization of calculations.

The modern industrial CZ Si crystal growth systems are characterized by high-Re (about $10^5$) 3D melt flows which necessitates the modelling turbulence effects. In our calculations, we have used the *OpenFOAM* Smagorinsky-Lilly LES model for an incompressible fluid with van Driest turbulence damping at solid walls and constant melt quantities [1]. The buoyancy forces were modelled in Boussinesq approximation. The calculations' results from a 2D axisymmetric heat transfer modelling for the whole system, e.g. [2], were used for the temperature calculation in the melt as boundary conditions.

In the present work the influence of different axisymmetric travelling EM fields on the melt flow was examined. The EM force density field in the melt was calculated by a 2D axisymmetric electromagnetic (EM) field model and interpolated for a 3D mesh for the HD calculations. To use EM volume forces in the melt flow modelling, we have developed a special *OpenFOAM* solver *czlesfoam*. The calculations were performed on several grids, with the finest grid having 242041 cells. The calculations had to be run by about 2000 s of the flow time, before the flow more or less stabilized. Subsequently the melt flow and temperature fields were averaged for 100 s of the flow time. Below an example of calculations is shown for the influence of an upwards-driving travelling field on the Si melt flow (left – EM force density, right – velocity field).



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## References

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