EU COST action P6 “Magnetofluiddynamics”
Working Group “ Use of magnetic fields in crystal growth”

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Use of magnetic fields in crystal growth

Numerical modelling of turbulent flows in industrial CZ silicon large crystal growth with magnetic fields, 2D and 3D analysis

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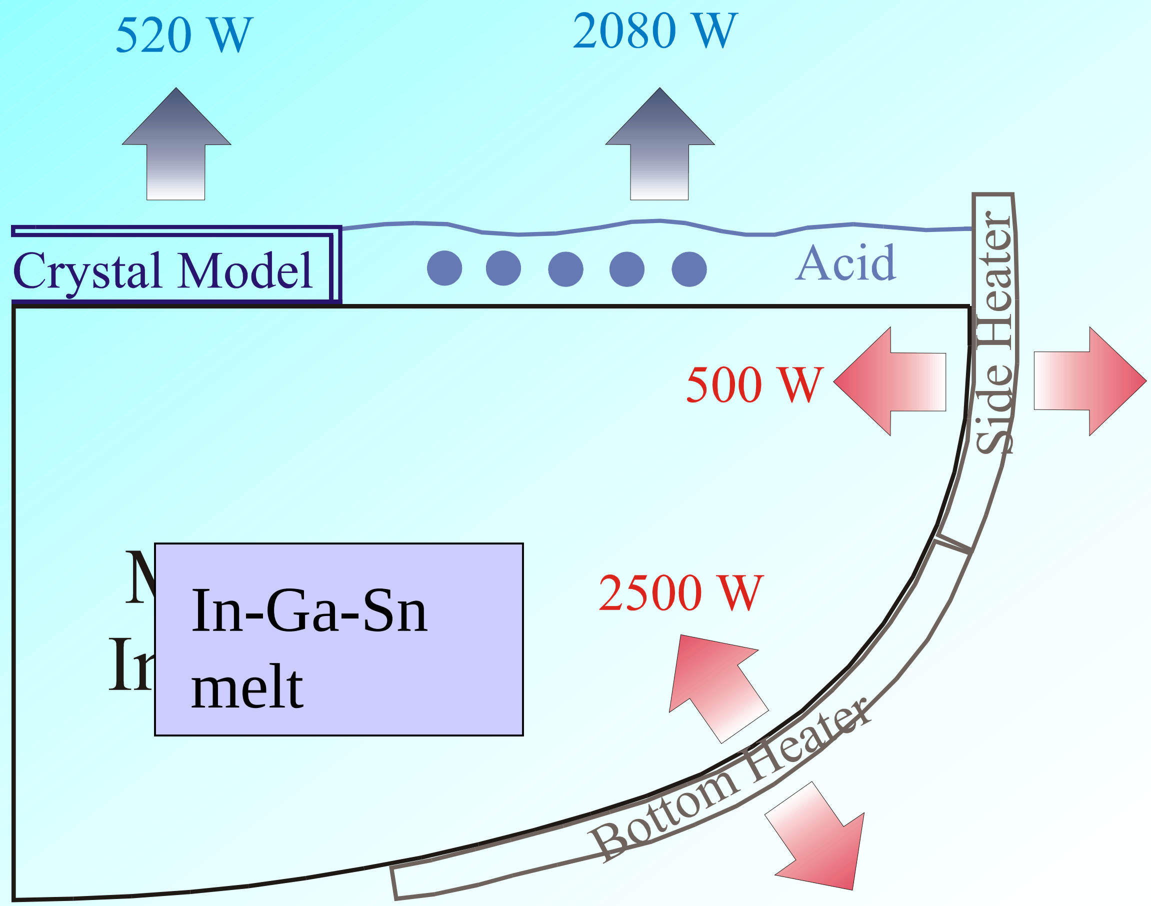
1. Modelled experimental system with In-Ga-Sn melt

Physical modelling with experimental system at ELMATEC Ltd, Dr. Gorbunov, Prof. Dr. Gelfgat, Institute of Physics, University of Latvia

Melt Properties

$$\rho = 6350\, kg/m^3$$
$$\mu = 0.0019\, kg/(m \cdot s)$$
$$C_p = 363.5\, J/(kg \cdot K)$$
$$Pr = 0.03056$$
$$\beta = 0.00007\ 1/K$$
$$\sigma = 3.3 \cdot 10^6\, 1/(\Omega \cdot m)$$

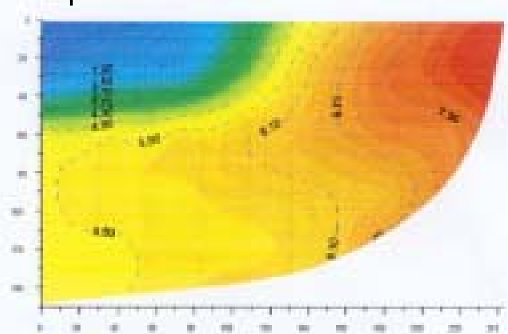


2. Calculation results for the case with motionless crucible

k – ε modified low-Re turbulence model (CFD-ACE package)

Experiment

a) Temperature



b) Temperature pulsations

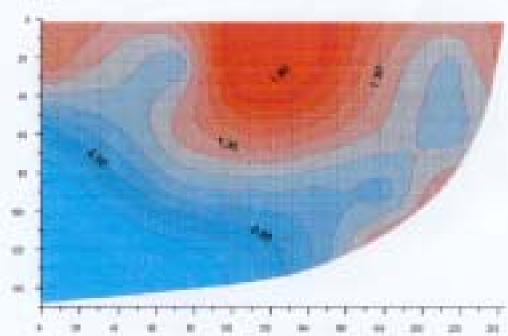
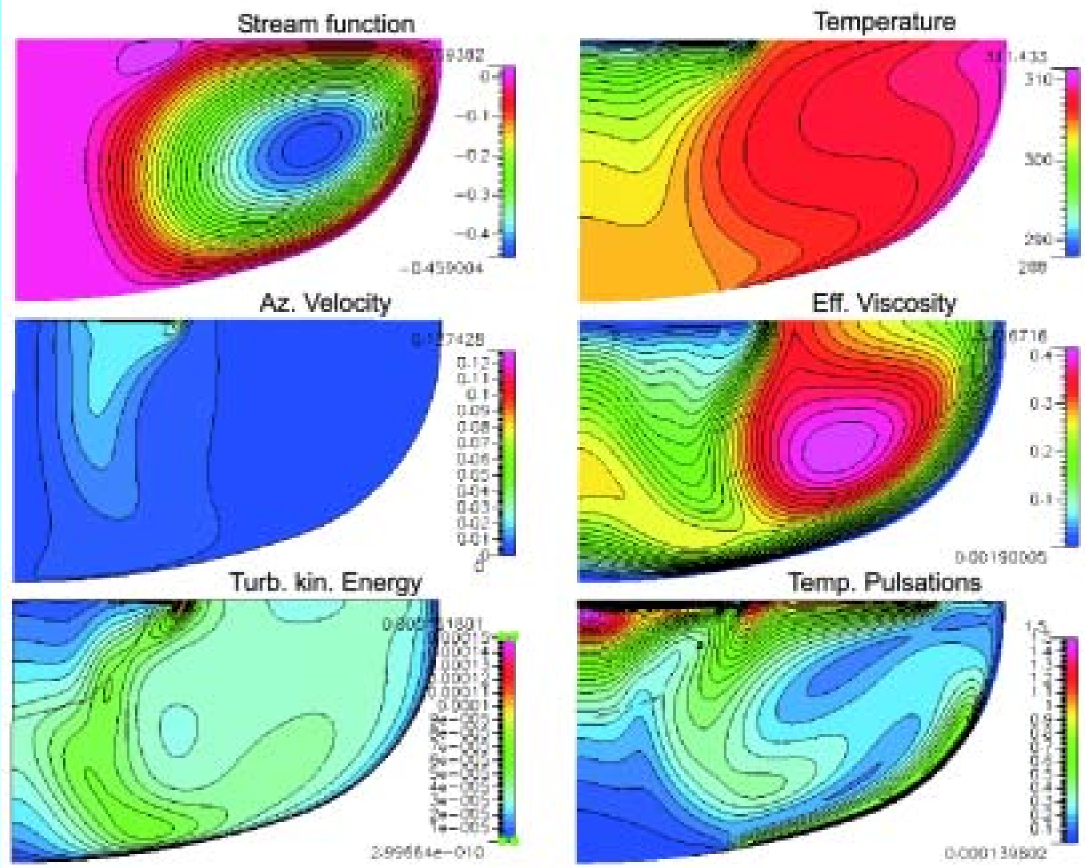


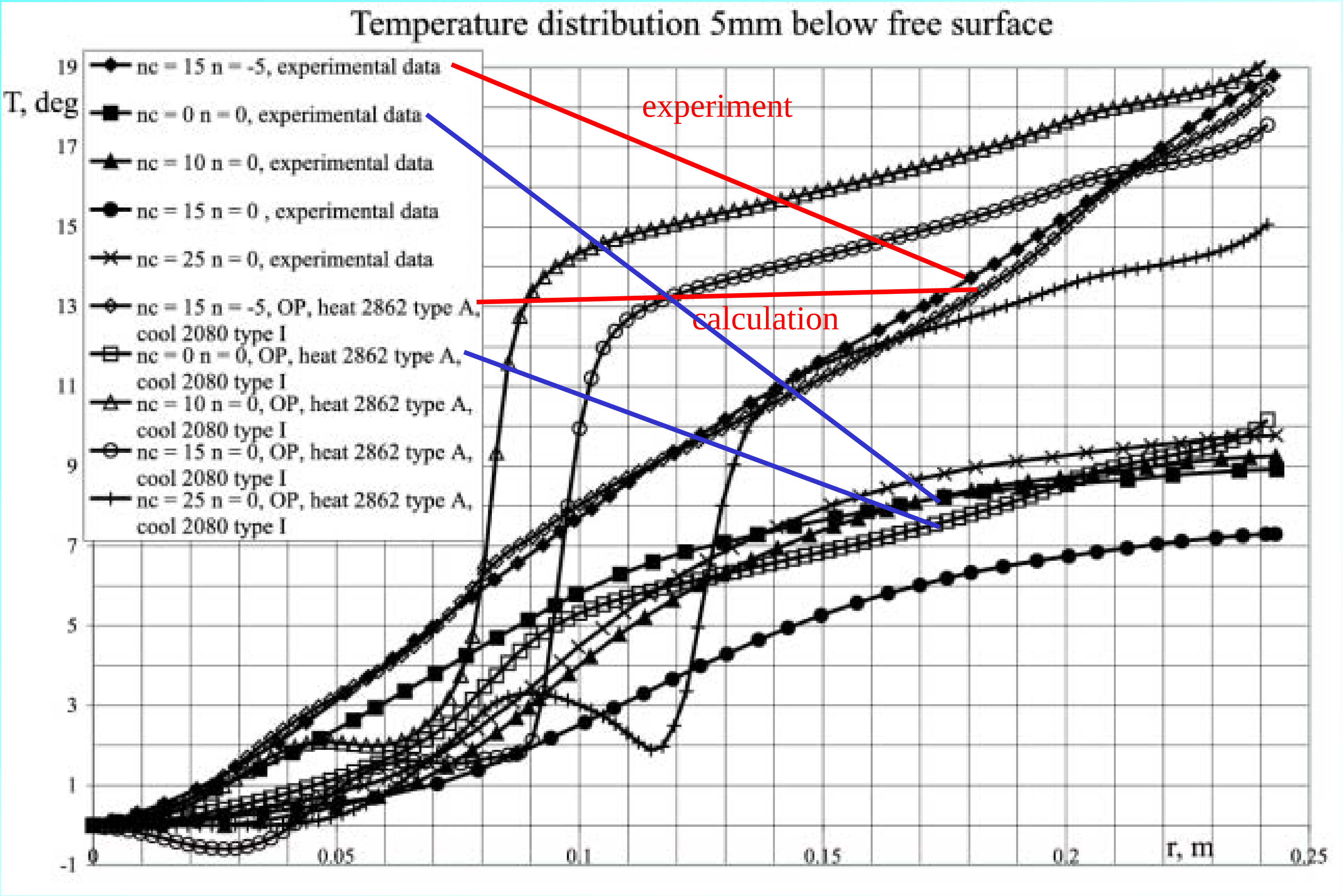
Fig.3.21. Isotherms in the melt (a) and root-mean square scatter T** (b) at n_c = 15 rpm, n = 0 (maximum value of temperature drop ΔT = 8 °C, maximum value of root-mean square scatter T** = 1.9 °C)

Calculation

Rotation: nc = 15 rpm, n = 0 rpm
Magnetic Field: no
Heat Flow, Heaters: P_{heat} = 2862 W, type A
Heat Flow, Free Surface: P_{heat} = 2080 W, type I
Pr = 0.025



Calculated and measured radial temperature distribution along free melt surface (5 mm below), cases with motionless crucible



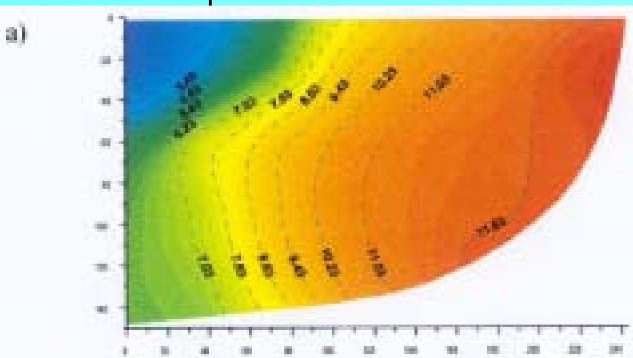
3. Calculation results for the case with alternating magnetic field

k – ε modified low-Re turbulence model (CFD-ACE package)

Experiment

Temperature

a)



Temperature pulsations

b)

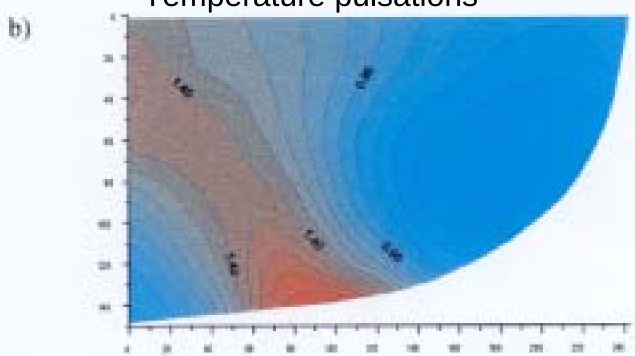
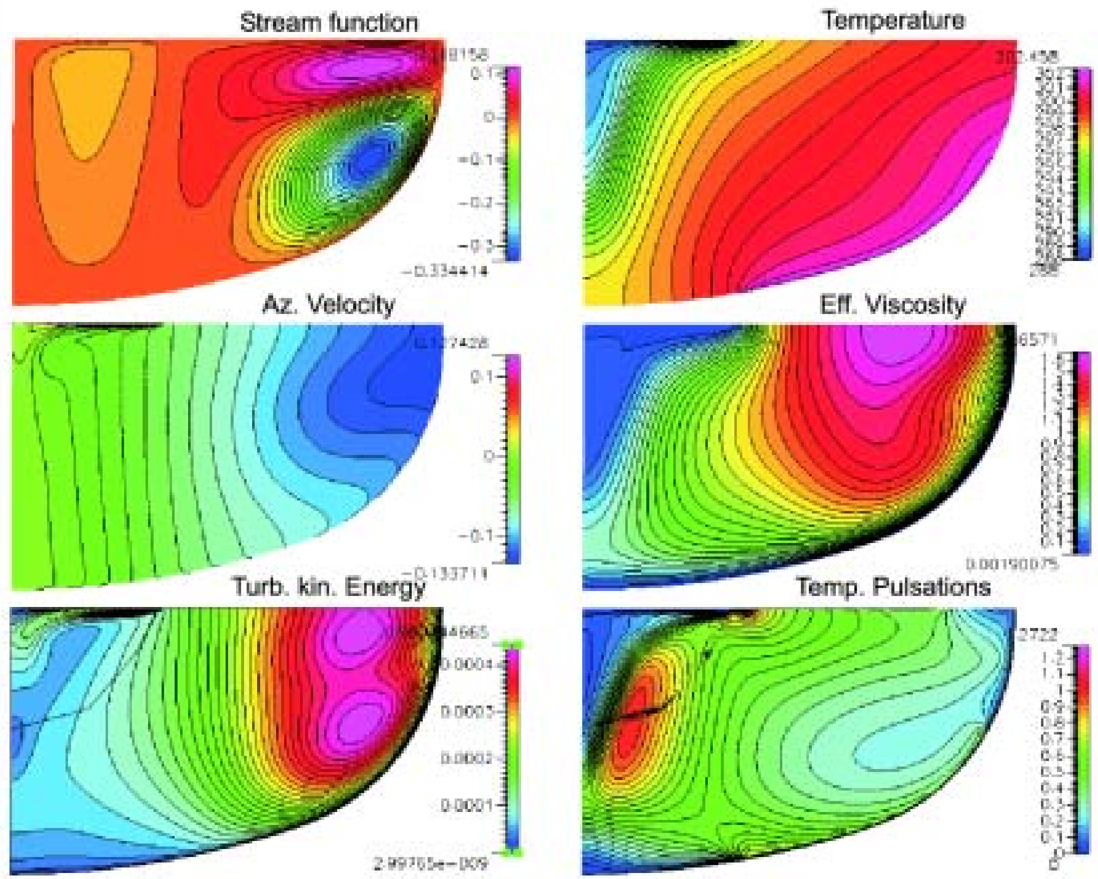


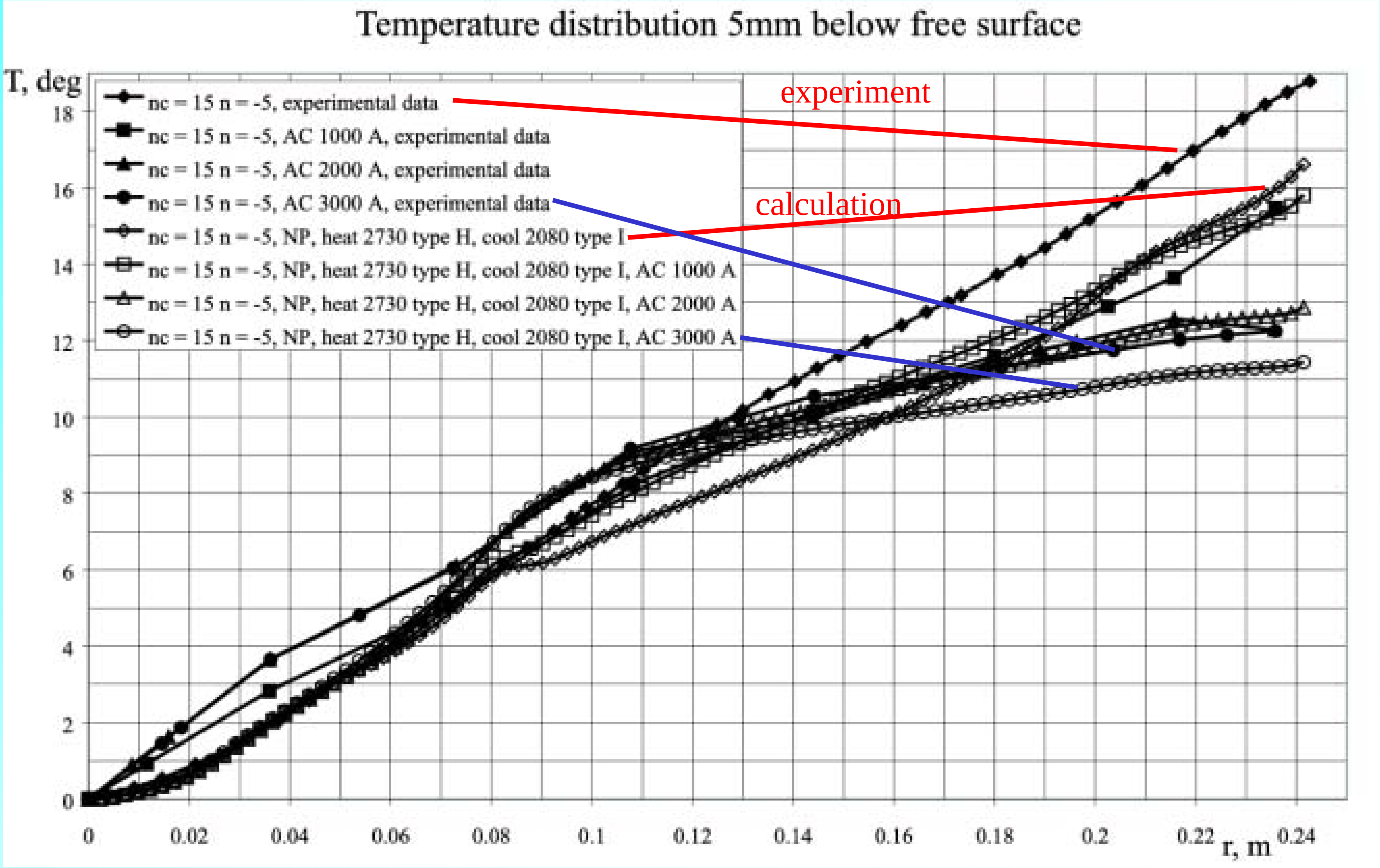
Fig.7.9. Isotherms in the melt (a) and root-mean square scatter T** (b) at n_c = 15 rpm, n = -5 rpm under the impact of an alternating magnetic field NI = 3000 A (maximum value of temperature drop ΔT = 12.4 °C, maximum value of root-mean square scatter T** = 2.3 °C)

Calculation

Rotation: nc = 15 rpm, n = -5 rpm
Magnetic Field: AC, 3000 Aw
Heat Flow, Heaters: P_{heat}= 2730 W, type H
Heat Flow, Free Surface: P_{heat}= 2080 W, type I
Pr = 0.03056



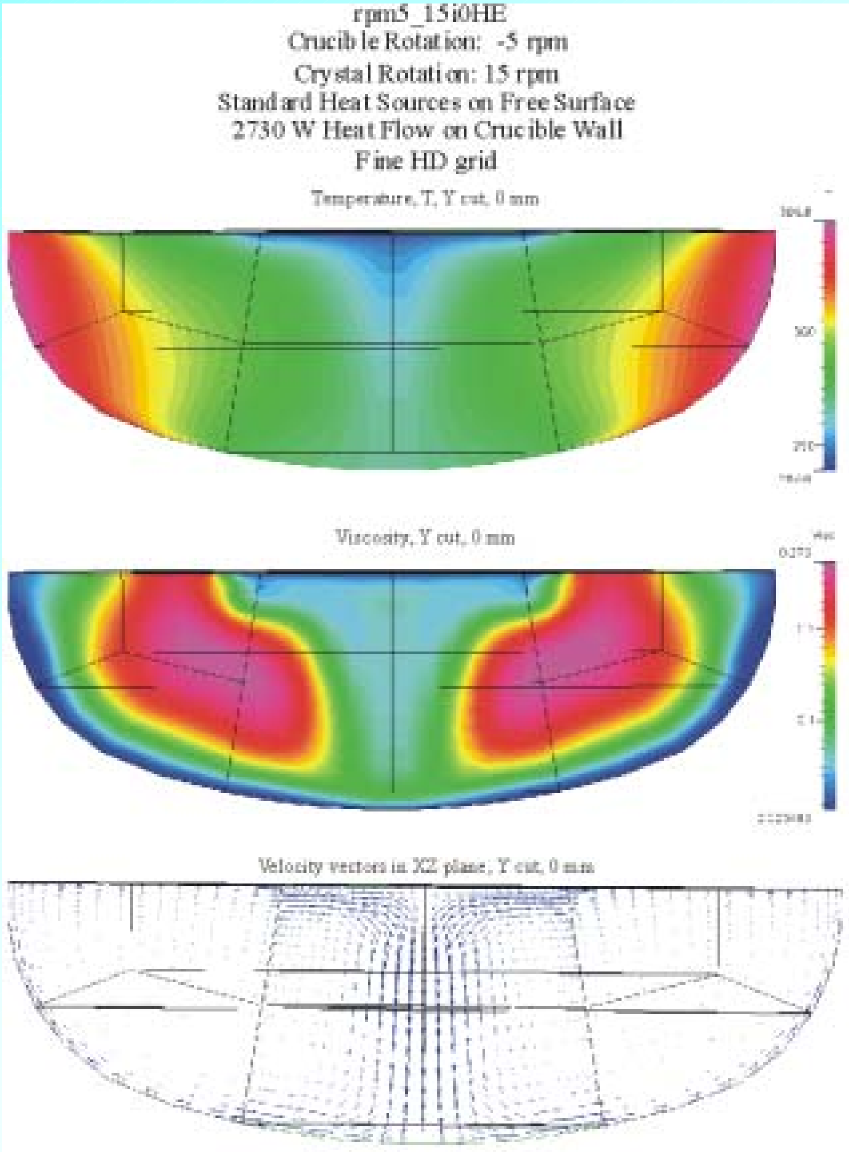
Calculated and measured radial temperature distribution along free melt surface (5 mm below), cases with alternating magnetic field



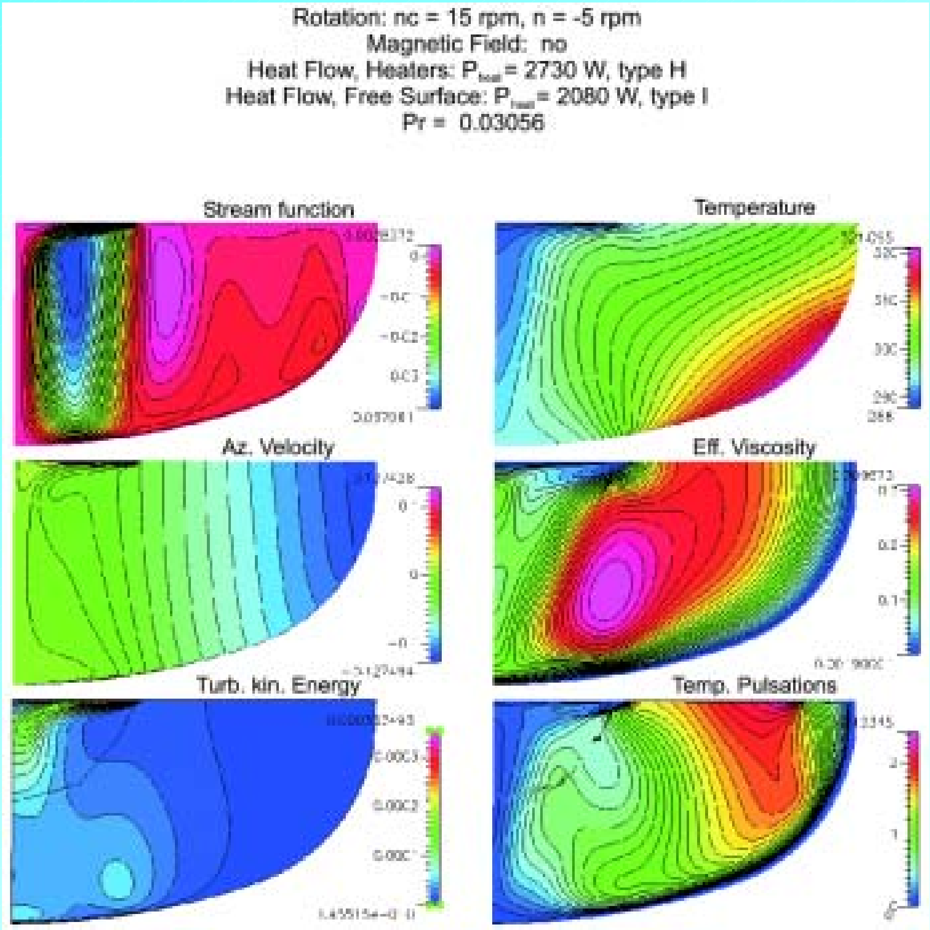
4. Comparison of 2D and 3D calculations

k – ε modified low-Re turbulence model (CFD-ACE package)

3D calculations



2D calculations



5. Conclusions

Summary of the results of comparisons between calculations(2D) and measurements for the temperature distribution in the melt

Absence of MF	
Proportional Rates	mean
Motionless Crucible	very bad
Motionless Crystal	very bad
TGC case	good

Presence of MF	
Travelling Field	good
AC Field	good
CUSP Field	rather good
AXIAL Field	bad