[1] - Laboratory for Mathematical Modelling of Environmental and Technological Processes
University of Latvia

[2] - Institut für Elektrothermische Prozesstechnik
Universität Hannover

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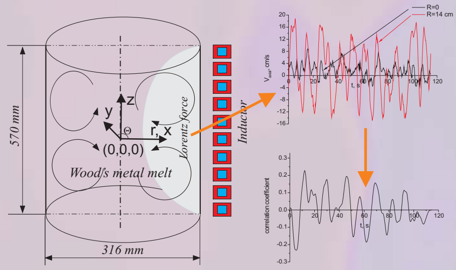
LES Modeling of Recirculated Flows in Crucible Furnaces

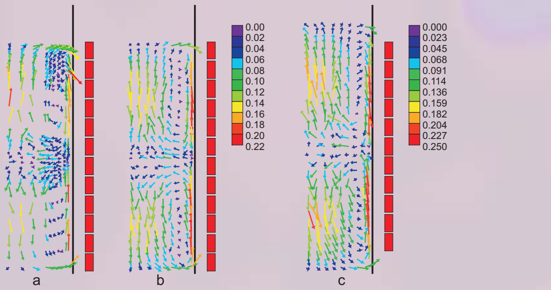
M. Kirpo[1], A. Jakovičs[1], E. Baake[2], B. Nacke[2]

1. Wood's metal flow in a cylindrical container (ICF)

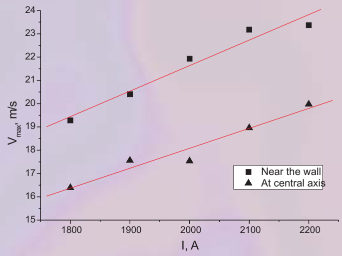
I = 1800 ... 2200 A
F ≈ 400 Hz
H = 570 or 620 mm
D = 316 mm
N_{ind} = 12 or 11

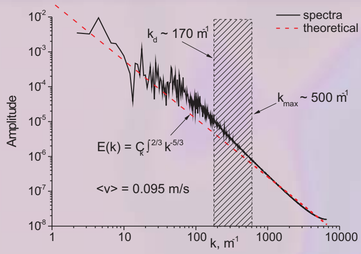


Velocity measurements are performed with two permanent magnet probes instantaneously for 2 minutes at each point. Low frequency velocity oscillations (*T*=10..15 s) are observed. The maximal intensity pulsations are placed in the near-wall region between the vortices



Averaged experimental data: velocity pattern a) 570 mm, year 1994; b) 570 mm, year 2006; c) 620 mm, 2006



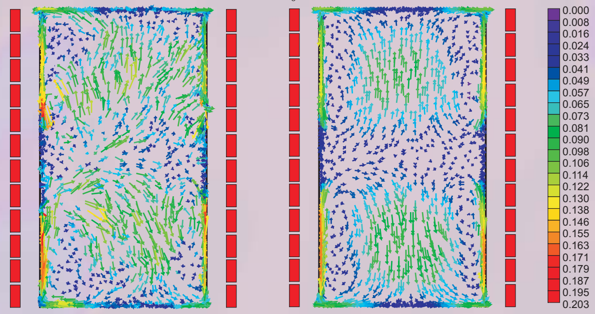


Characteristic velocity dependence on current is linear: *v*~ *I.* Calculated turbulent energy spectra

$$E(k) = C_k \varepsilon^{2/3} k^{-5/3}$$

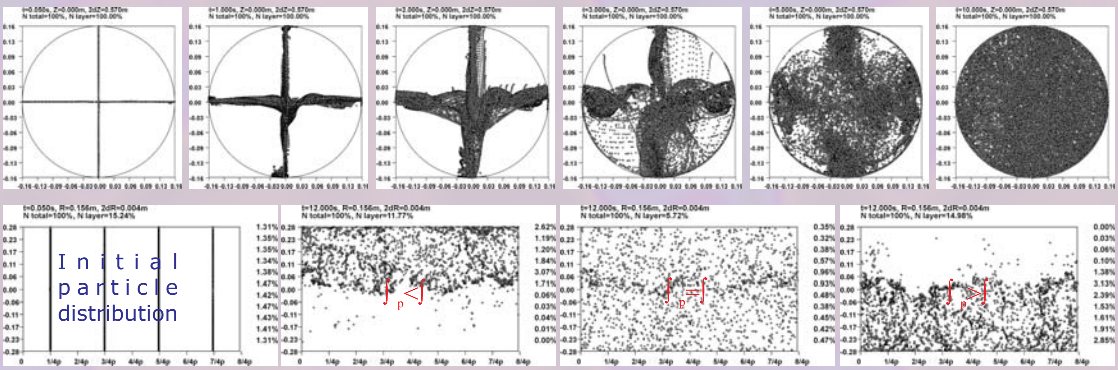
is in good accordance with the theoretical (red dashed line), where the turbulent dissipation ε:

$$\varepsilon = 2\nu \int_0^\infty k^2 E(k)\,dk$$



3D LES transient simulation, instantaneous (*t* =30 s) and averaged velocity vectors (*I* = 2000 A, *H* = 570 mm)

2. Unsteady particle transfer (*St* ≈ 0.044)

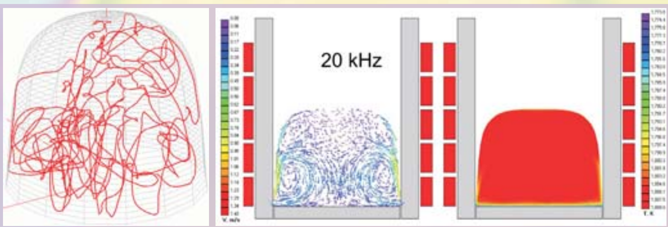


Modeling unsteady Lagrangian particle transport allows determining efficiency of turbulent mixing. Development of preferential particle concentration shows importance of the particle density. Particle interaction with fluid is influenced by the Stokes number:

$$St = \frac{\rho_p d_p^2 U_0}{18 \mu L_0}$$

3. LES parameter study of cold crucible furnace (IFCC)

LES parameter study of the IFCC were performed using 3D ANSYS EM model. Averaged velocity, temperature distributions and overheat in the melt for different inductor frequencies and crucible diameters are found. Increasing inductor frequency the total system power decreases, while overheat temperature becomes higher.



4. Conclusions

- Performed LES computer simulation have the same characteristics (characteristic velocity values and vortex structure) as the measured mean flow. Wavenumber space experimental and computational spectrums are in accordance with the Kolmogorov's theory.
- LES calculated temperature distribution in IFCC does not have large temperature gradients. Angular dependence of Lorentz force distribution and Joule heat sources increases computed average temperature of the melt in IFCC.
- Lagrangian particle tracing shows high intensity of the convective mass exchange in both IFC and IFCC. Particle and fluid density difference is found to be very important parameter, which determines particle preferential concentration. Particles of larger sizes are better accumulated in the near-wall region.