LMD End of year meeting. December 15. 2025

LMD research in University of Latvia 2025

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This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Progress on LMD activities in 2025

IPUL activities in 2025

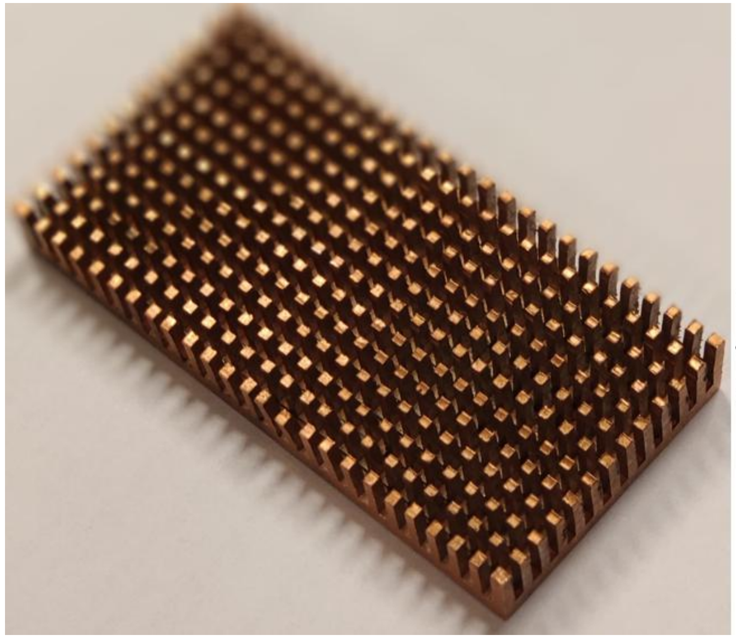
- Study of MHD flows in capillary porous systems
- Investigation of thermoelectromagnetic phenomena in liquid metal CPS
- Evaluation of potential of free flowing LM film system and assessment of bubble refinement via ultrasound

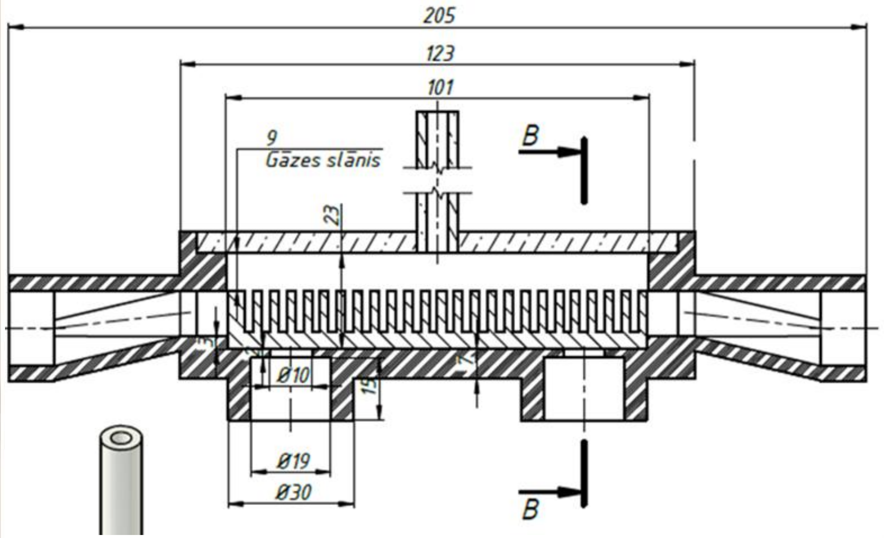
Recent publications:

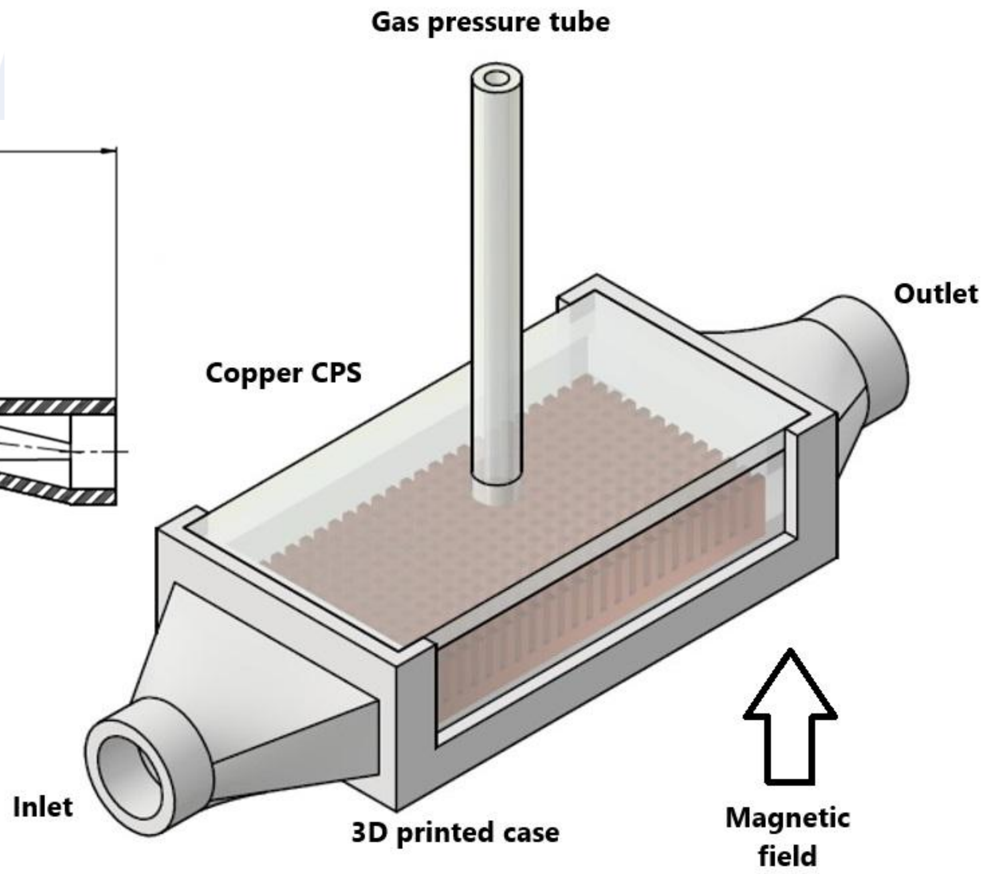
- Kaldre, I.; Kleinhofs, A.; Felcis, V.; Dzelme, V. Static Magnetic Field Impact on Laser Weld Bead Morphology of Sn-10%wt.Pb Alloy. *Metals* **2025**, *15*, 1344. https://doi.org/10.3390/met15121344
- Kaldre, I., Felcis, V., Krastins, I. *et al.* Model Experiment for the Investigation of Thermoelectric Magnetohydrodynamics in Metal Additive Manufacturing. *JOM* **77**, 6038–6049 (2025). https://doi.org/10.1007/s11837-025-07458-0
- L. Buligins, I. Bucenieks, I. Grants, I. Kaldre, K. Kravalis, O. Mikanovskis. MHD Flow in Simple Cubic Periodic Array Geometry. Journal of Fusion Energy. (2023)42:55 https://doi.org/10.1007/s10894-023-00390-8
- I.Kaldre, V.Felcis. THERMOELECTRIC MHD EFFECTS IN METAL ADDITIVE MANUFACTURING. PAMIR conference, September 15-19, 2024.

MHD flow in capillary porous systems

Copper capillary porous system model is placed inside 3D printed case and it is tested in magnetic field, measuring the pressure drop and flow rate depending on the magnetic field direction and strength. For better understanding of the physics the process is numerically simulated. It is found out that magnetic field can significantly affect the pressure flow rate behavior.

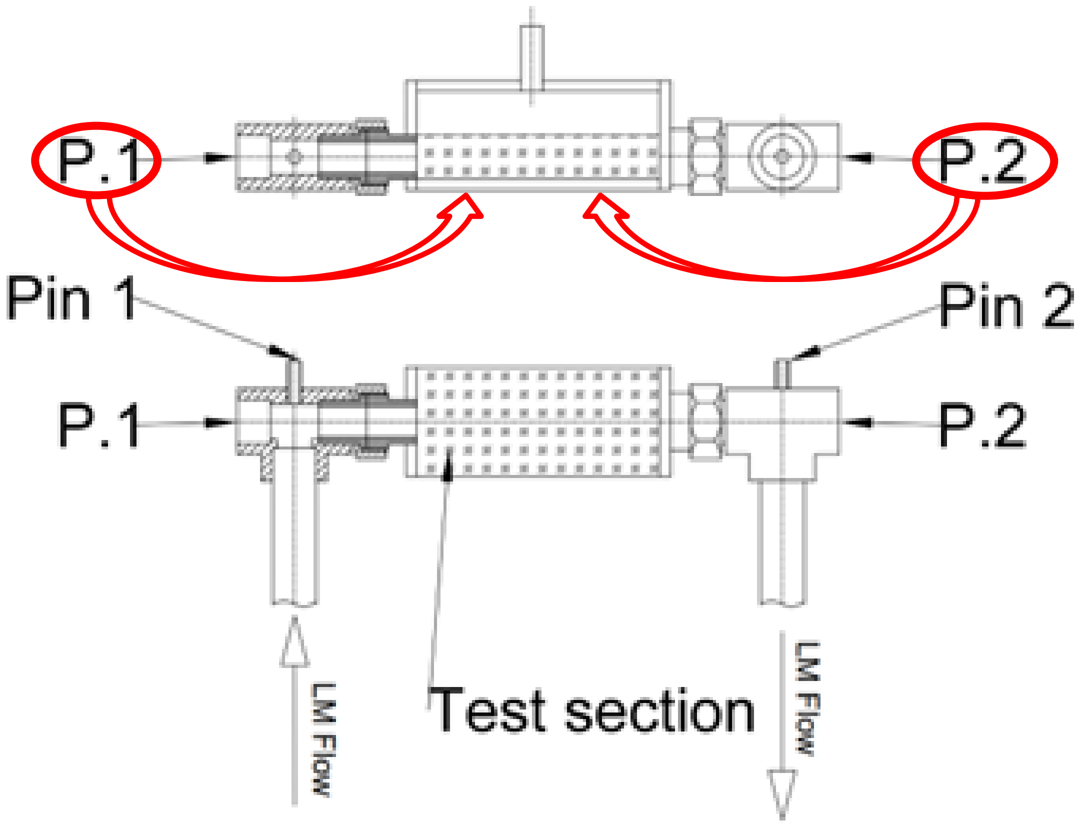






Copper CPS (h=10 mm, cell 2x2 mm, plastic case

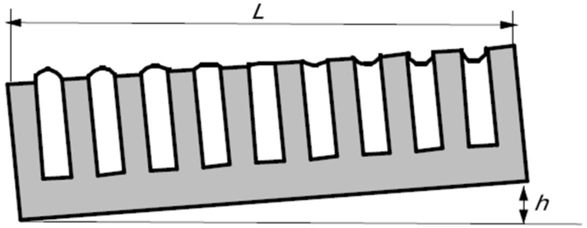
Test section modification

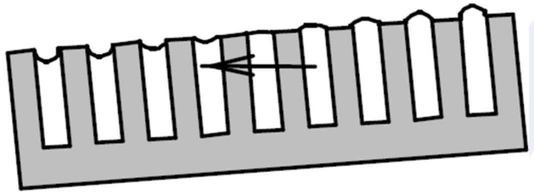


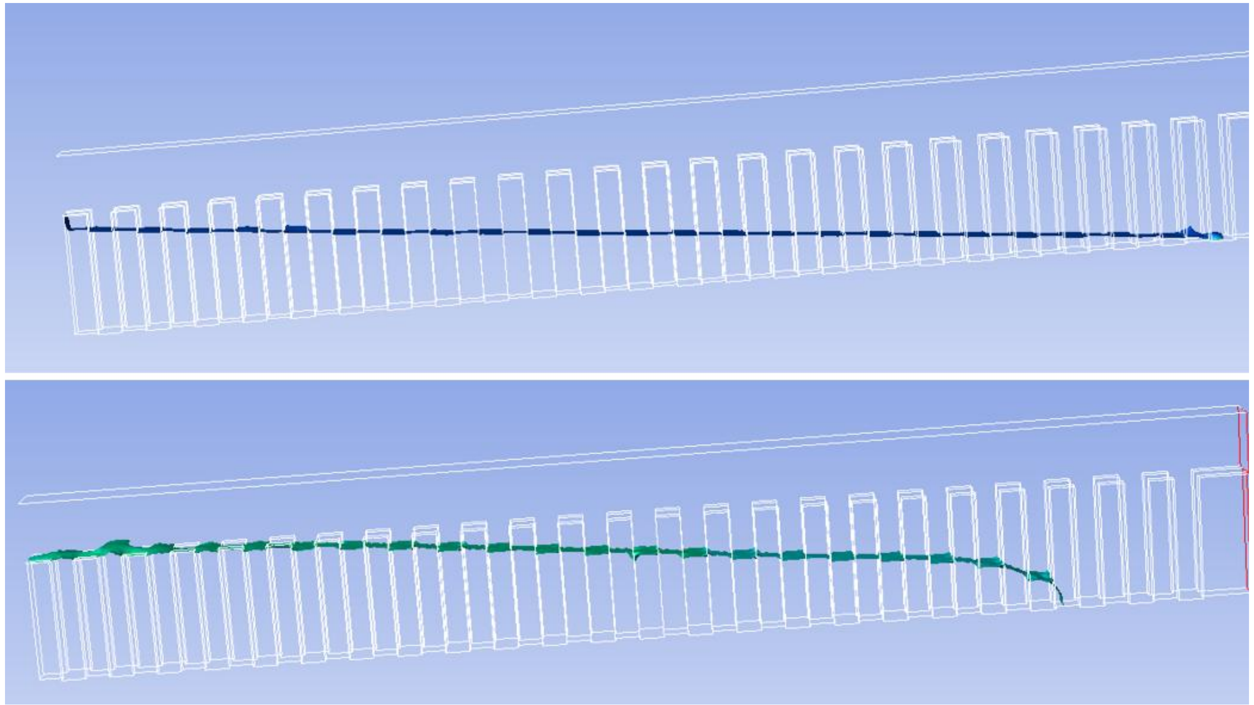
- Current pressure measurement positions were not optimal, influenced by LM level variation, particularly at the TS outlet
- Mitigation - moving pressure measurement points to the bottom of test section
- Increasing the number of pressure measurement points till 3-5
- This will allow indirect LM height estimation over TS length
- Increase the quality of 3D printed parts to decrease adhesion of LM at the spheres surface in form of thin films, thus enhancing free surface position determination

Analysis of flowrate and free surface flow

For better understanding of the physics the process is numerically simulated. It is found out that magnetic field can significantly affect the pressure flow rate behavior.







Flow estimate in a conducting matrix

- Negligible el.potential → simple e.m. braking force expression

$$\sigma\, v\, B^2$$

- Flow-supporting hydrostatic pressure gradient

$$\rho\, g\, h/L$$

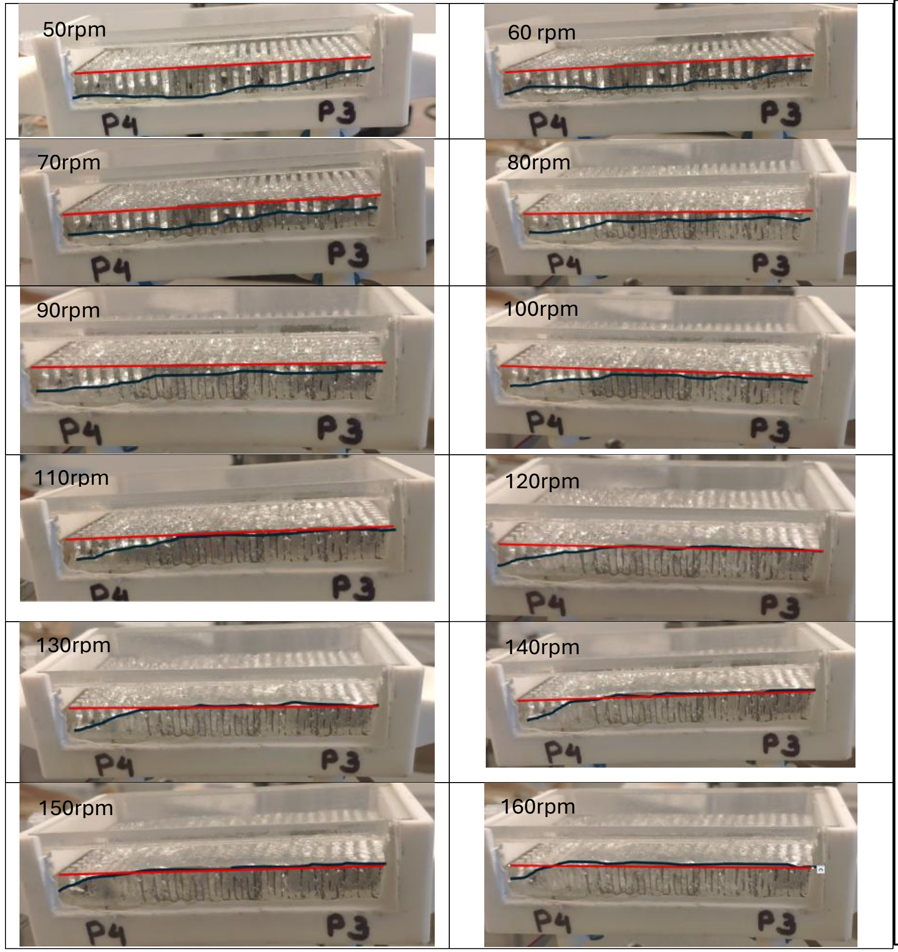
- Velocity

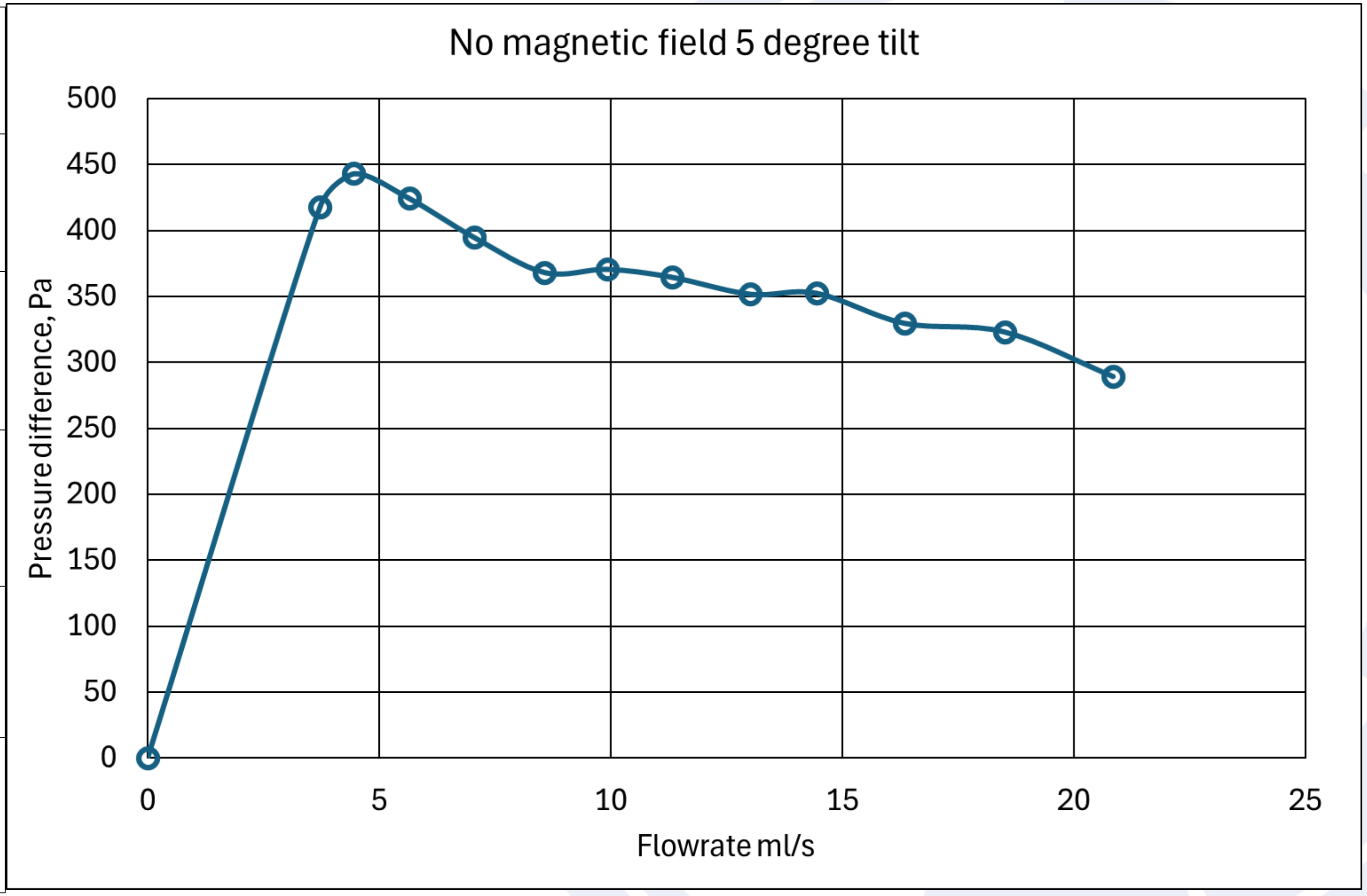
$$v \sim \rho\, g\, h \,/\, (L\sigma\, B^2)$$

- About 2 mm/s at h/L=0.04, B=0.2 T

Free surface without and with surface tension for 5 degree inclined test section

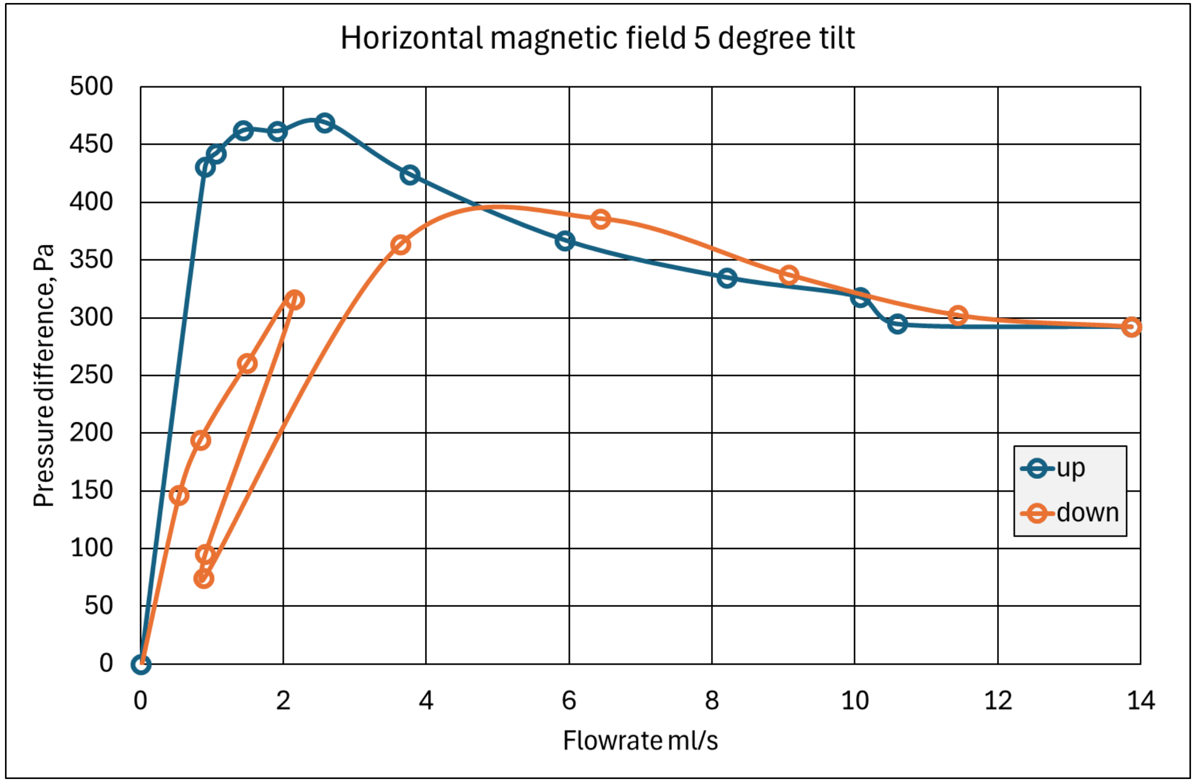
Free surface shape vs EM rpm (pressure)

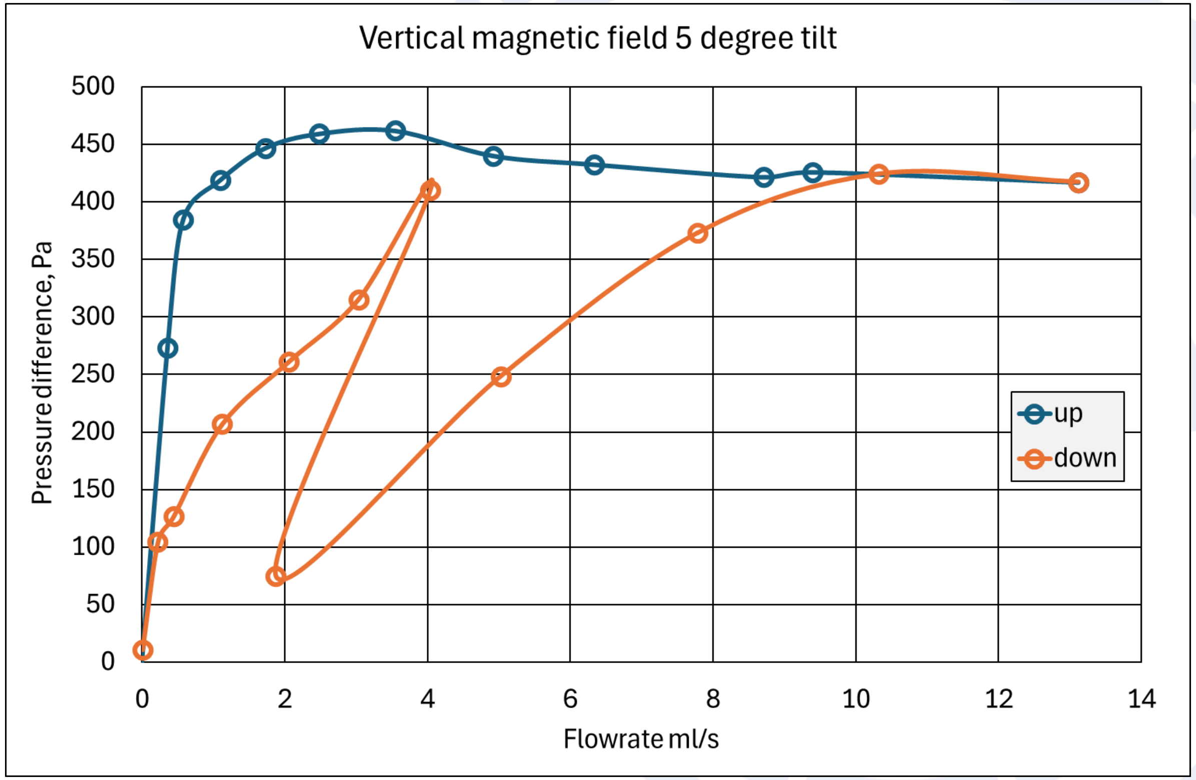




Experimentally observed free surface shape and pressure-flowrate curve at B= 0.33 T

Pressure difference vs flowrate B=0.33 T





Evaluation of potential of free flowing LM film system and assessment of bubble refinement via ultrasound

- Formation of hydrogen bubbles is a problem for the divertor concept based on liquid metal CPS. As these bubbles pop they cause plasma contamination.
- Objective of this work is to assess potential of electromagnetically excited power ultrasound to mitigate this problem.
- Power ultrasound is known to cause cavitation that, in turn, leads to bubble splitting. Smaller bubbles rise slower providing more time for the metal flow to carry them away. Besides, smaller bubbles would cause smaller ejected droplets, if any. Power ultrasound can be excited in a conducting media by crossed alternating electric and steady magnetic fields

Rayleigh–Plesset equation or Besant–Rayleigh–Plesset equation is a nonlinear ordinary differential equation which governs the dynamics of a spherical bubble in an infinite body of incompressible fluid

$$R\frac{d^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+\frac{4\nu_L}{R}\frac{dR}{dt}+\frac{2\sigma}{\rho_L R}+\frac{\Delta P(t)}{\rho_L}=0$$

For q = 0.1 MW/m2 at w = 0.8 106 s-1 the alternating electrical field amplitude E is estimated from

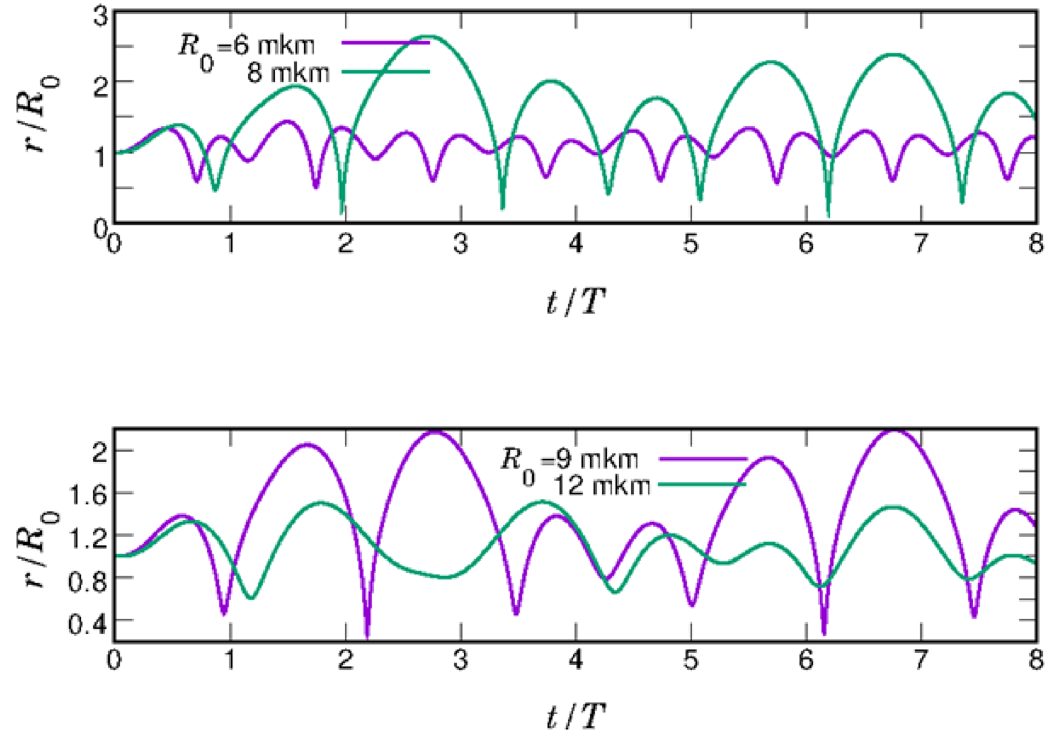
$$E = (4q(0.5\text{w}m_0/s_{Cu})^{1/2})^{1/2} \approx 8 \text{ V/m}.$$

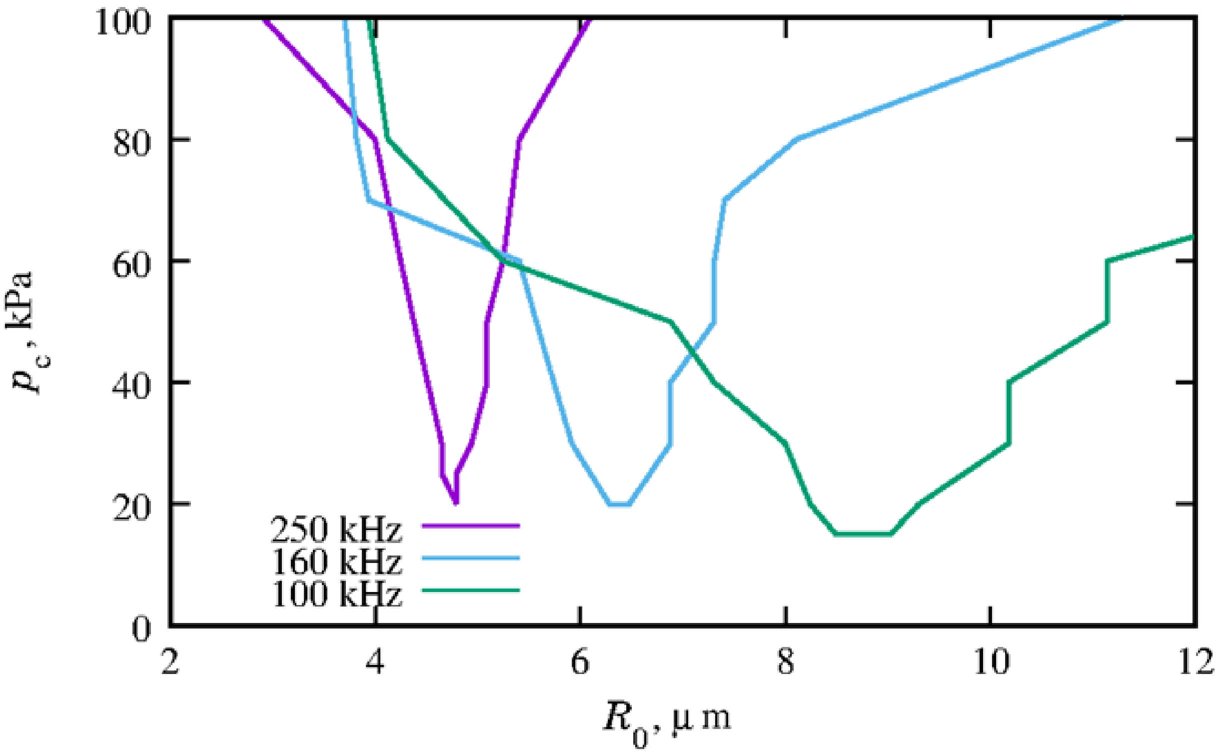
The corresponding maximum electromagnetic pressure amplitude can now be estimated as

$$p_A \approx EsBd \approx 10^5 \text{ Pa}$$

In static magnetic field with B = 6 T. The corresponding cavitating bubble radius is obtained from R_0 ≈4.7 µm and its resonance frequency is about 270 kHz

Numerical analysis of the bubble stability





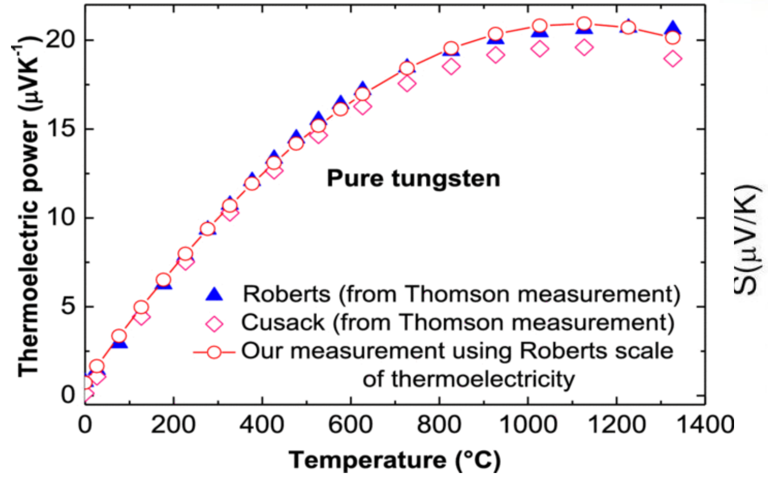
The conditions of bubble surface stability are evaluated by equation (17) in Ref.[Plesset]. As pressure amplitude p_A was increased, this condition was met in a certain range of initial bubble radii. Figure 1. displays examples of computed transient bubble radius near cavitation inception. Figure 2. displays the computed threshold values of the pressure amplitude as a function of bubble initial radius for three different frequencies

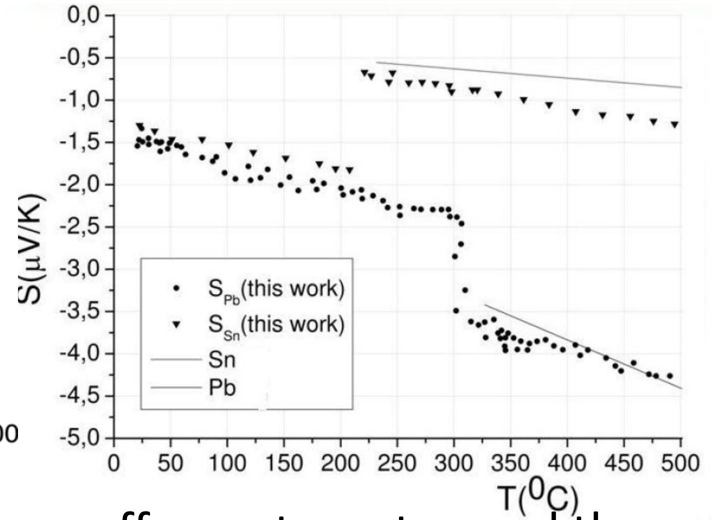
Thermoelectric magnetohydrodynamics may have significant effect on the liquid metal flow and free surface

- Ohm's law $$\frac{\boldsymbol{J}}{\sigma} = \boldsymbol{E} + \boldsymbol{u} \times \boldsymbol{B} - \overbrace{\boldsymbol{S\nabla T}}^{Seebeck\ effect}$$
- Navier-Stokes equation $$\rho(\boldsymbol{u} \cdot \boldsymbol{\nabla})\boldsymbol{u} = -\boldsymbol{\nabla p} + \mu\nabla^2\boldsymbol{u} + \overbrace{\boldsymbol{J} \times \boldsymbol{B}}^{Lorentz\ force} + \boldsymbol{f}$$

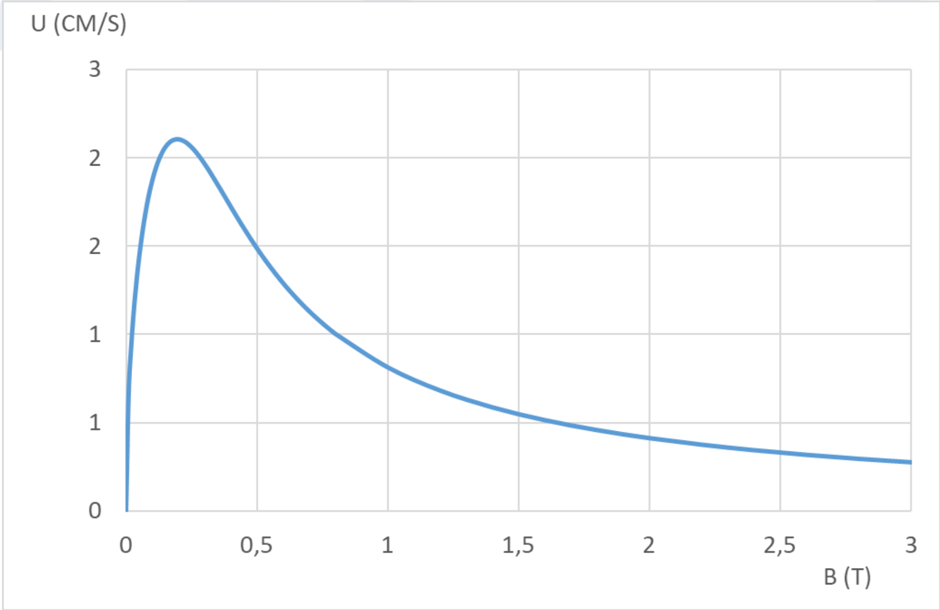
Applied magnetic field introduces two new volume forces

$$\sigma S \nabla T \times \vec{B} \qquad \sigma \vec{u} \times \vec{B} \times \vec{B}$$



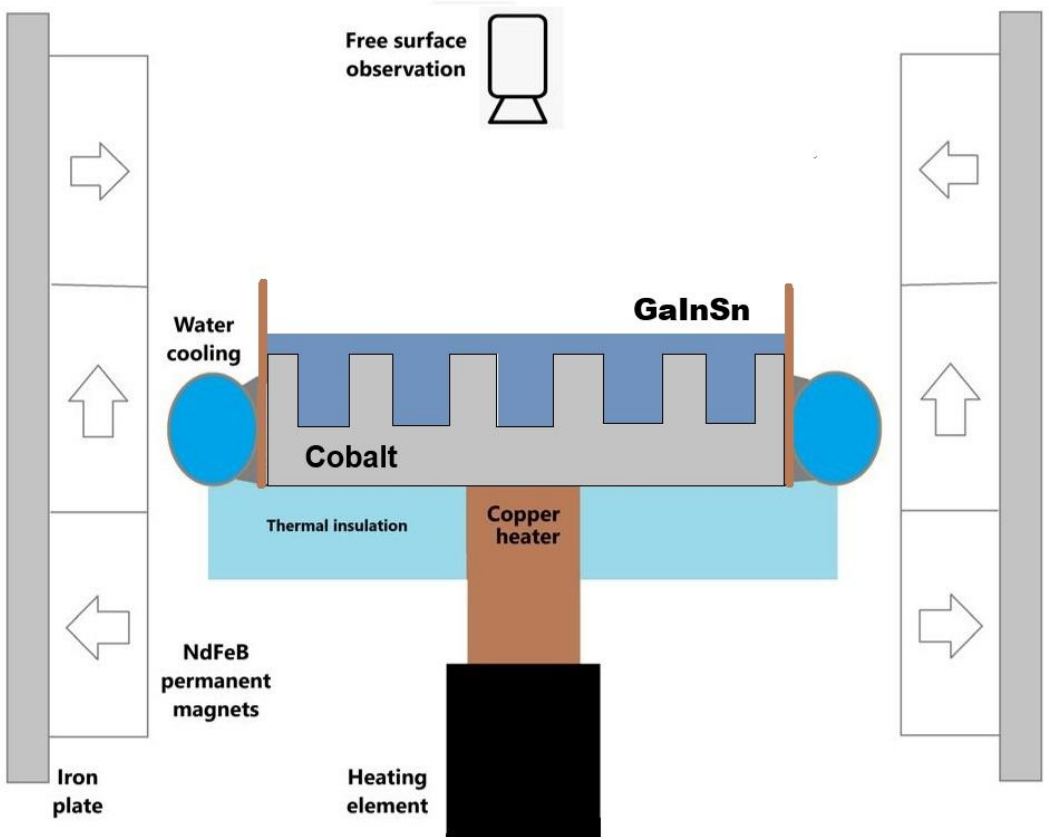


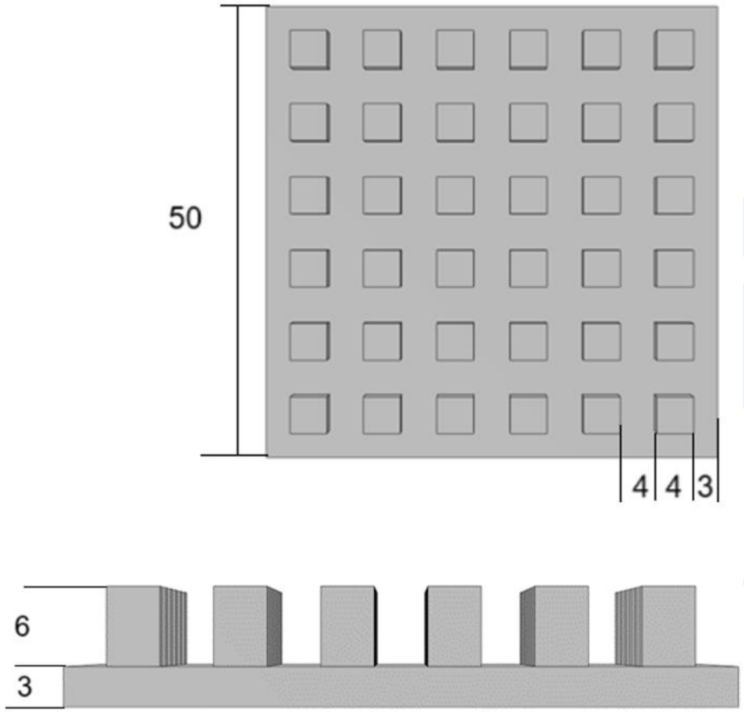
Absolute thermoelectric power off pure tungsten and the tin and lead. (Cobalt S=-25 μV/K)

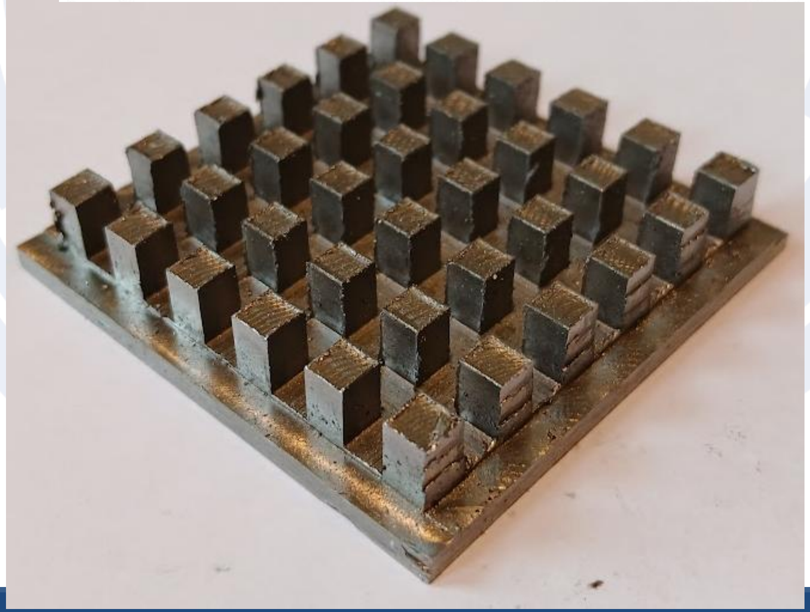


Characteristic TEMC velocity. P=20 μV/K, l= 3 mm, grad T=1 K/mm

Thermoelectric MHD flow experiment







Experiment objectives:

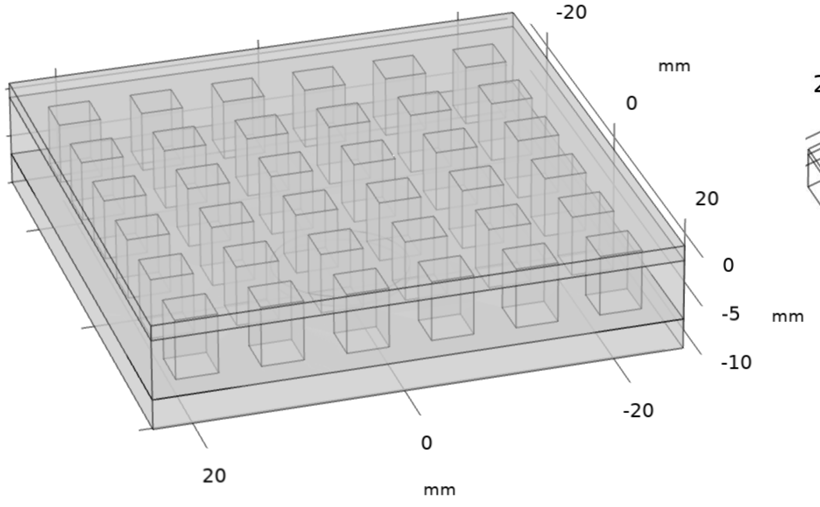
✓ Observe the flow at different field orientations and strength

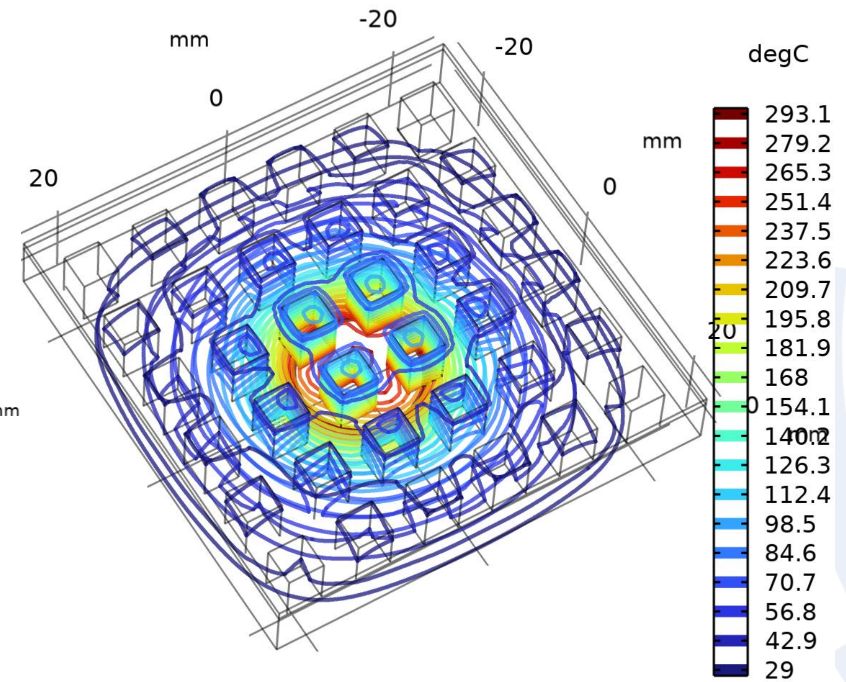
✓ Determine characteristic velocity vs temperature difference

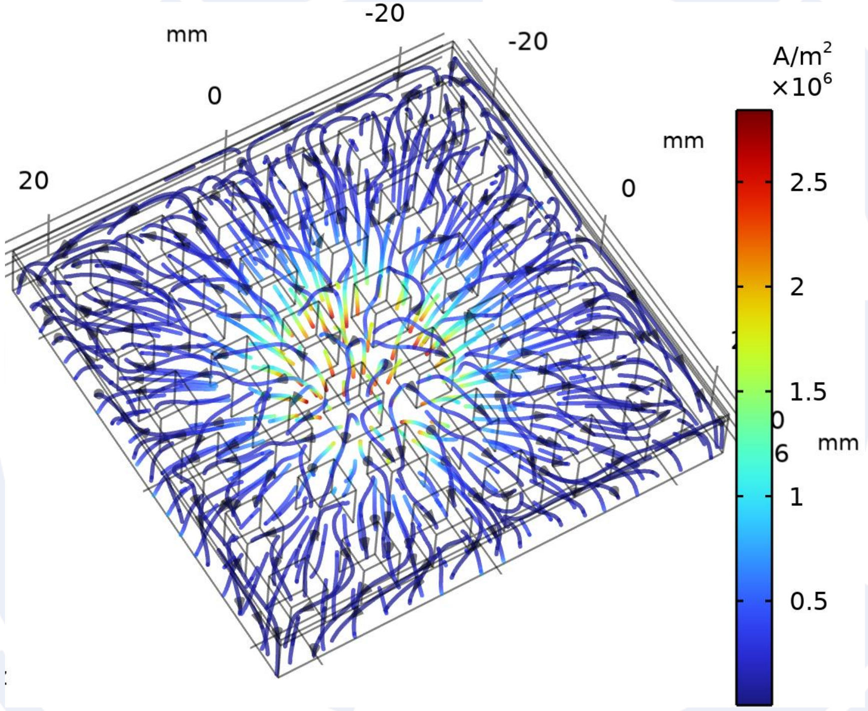
✓ Use this experiment as a scale model for ralistic CPS.

Numerical simulation results

Multiphysical numerical model is made using COMSOL Multiphysics. Thermal, electromagnetism, fluid flow model is developed

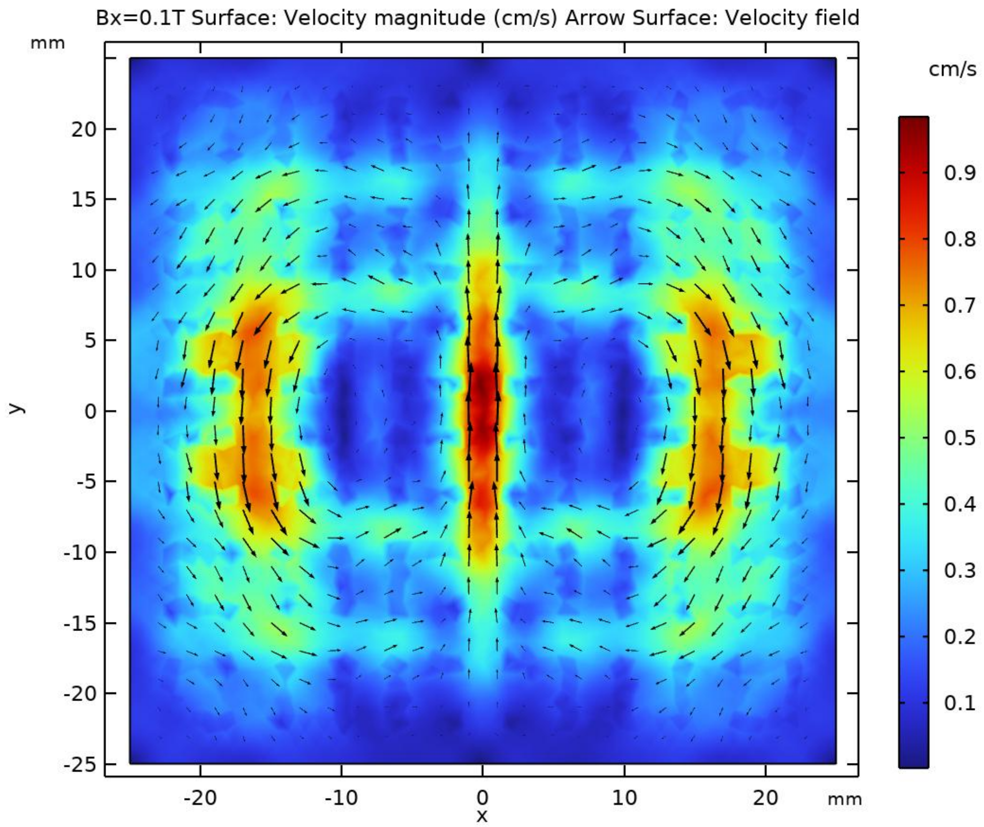


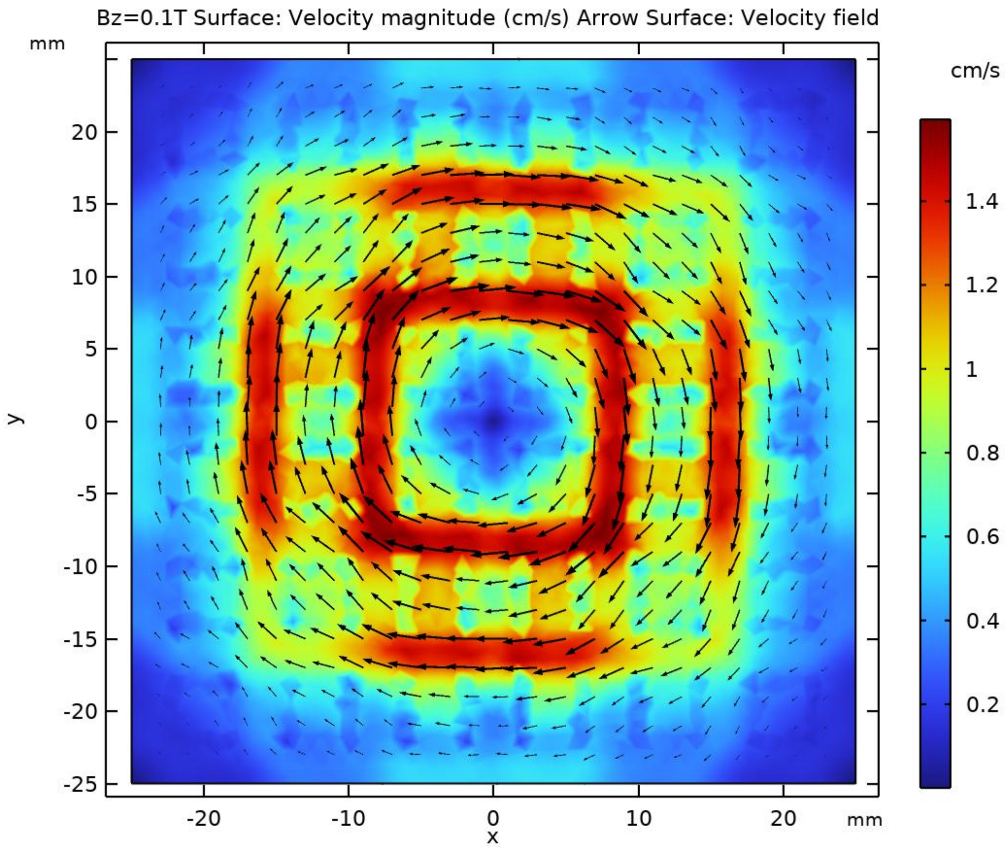




Numerical simulation geometry, temperature distribution and thermoelectric current distribution

TEMC flow at axial or transverse magnetic field



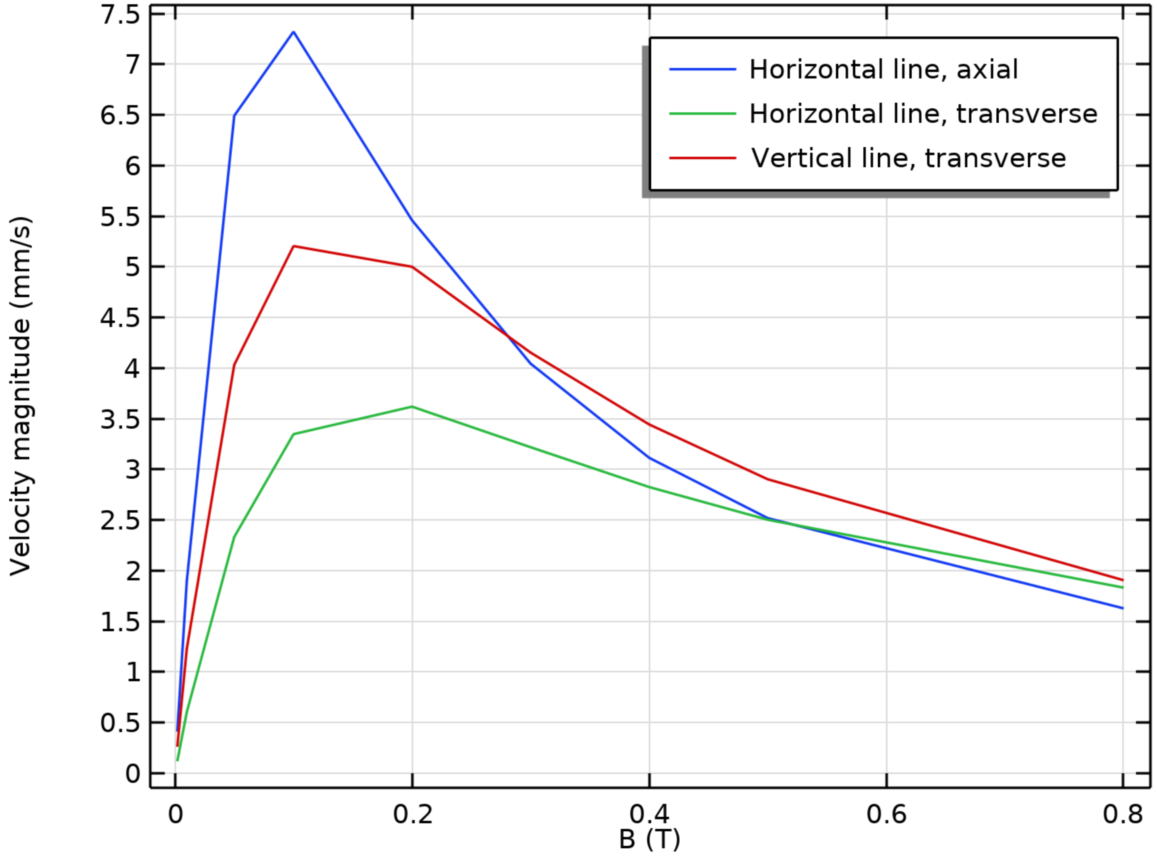


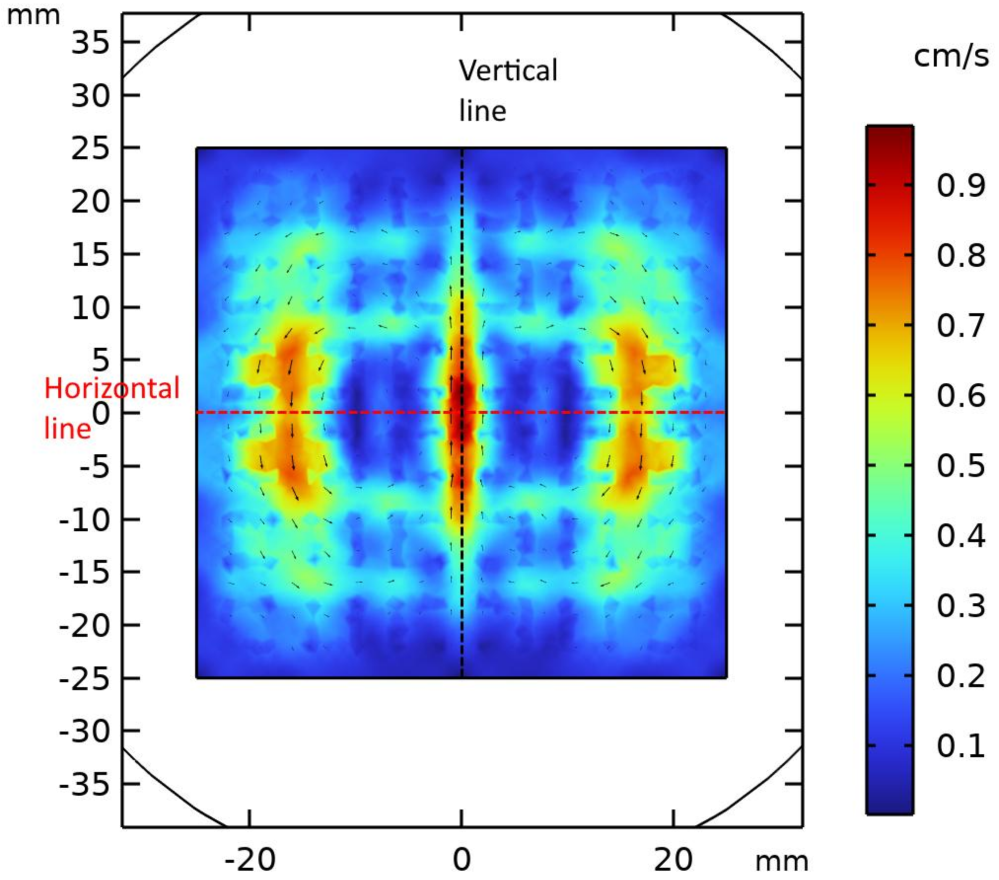
Bx=0.1 T

Bz=0.1 T

Numerically calculated TEMC flow in cobalt mesh

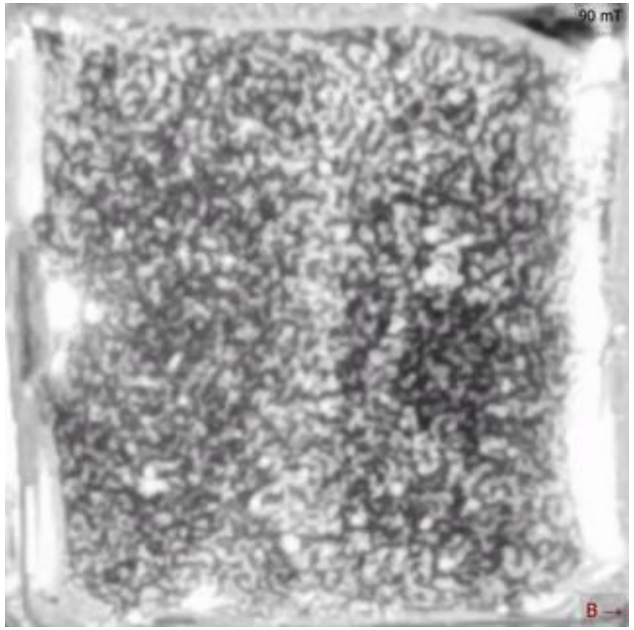
Parametric model

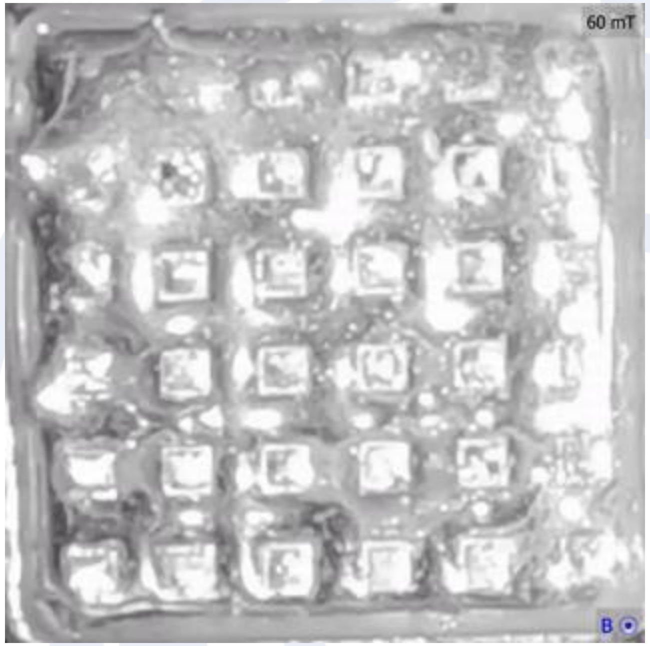




Calculated velocity field on the liquid metal surface (1mm). Velocity dependance on magnetic field.

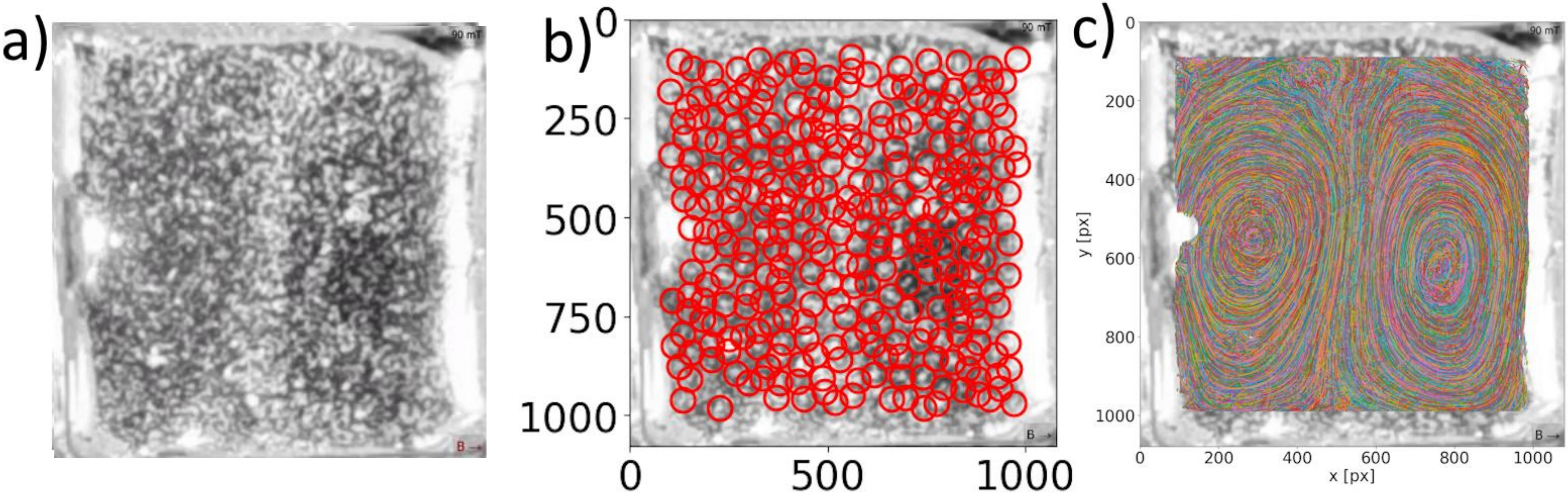
Experimental results





Transverse magnetic field B=90 mT, Axial magnetic field B=40 mT, Liquid metal flow in the mesh B=60 mT.
Velocity measurements are used to scale the physical processes and validate numerical models. Experiments shows the significance of the TEMC in liquid metal flow and heat transfer.

Surface bubble tracing to determine velocity field (Trackpy)



Surface flow tracking: a) Video frame, b) particles to be traced, c) surface velocity field.
Experimental challenges. Development of the methodology for smaller scale experiments.

Plans for 2026 and beyond

- **1. ISSP-UL: numerical and analytical study of thick flowing films and bubble refinement**
- **2. ISSP-UL: experiments on Ga loop with free surface stability with micro-channel/CPS flow**
- **3. ISSP-UL: design of liquid metal pump and flowmeters for LiMeS-PSI**

- **Analysis of the MHD flow in capillary porous systems**. It is planned to continue experimental work with various 3D capillary porous system models and investigation of their behavior under magnetic fields. Results will be compared with numerical models and scaled force the processes in plasma chamber. This research will also be focused on free surface investigation and to estimate the role of wetted/non-wetted surface.
- **Analysis of free flowing liquid metal films and bubble mitigation with ultrasound.** This approach allows us to reduce bubble problem by increasing metal flow speed and refining bubbles, thus increasing their residence time. Fast flowing LM film in high magnetic field is a complex MHD problem to study.
- **Experimental and theoretical investigation of the thermoelectric phenomena** and its role into realistic conditions. It is planned to continue small scale model experiments with cobalt/GaInSn and with W/Sn. Realistic geometry experiments, when known.

Conclusions

- TEMC motion is scale model is demonstrated and quantified
- Numerical model validation and scaling works well
- Different magnetic field orientations causes different flows.
- At relatively small magnetic field maximum velocity is reached
- Ultrasound bubble refining is feasible if moderate AC magnetic field can be applied to liquid metal in presence of high DC field.
- Experiments are influenced by free surface oxidation
- Capillary forces interaction with solid matrix lead to hysteresis of free surface shape and, consequently, to hysteresis of P-Q curves
- Movement of free surface (thus changing cross-sectional area) leads to non-monotonous pressure difference dependence on flowrate, particularly, if free flowing layer is formed