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LMD research in IPUL 2023

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Progress on LMD activities in 2023

IPUL activities in 2023

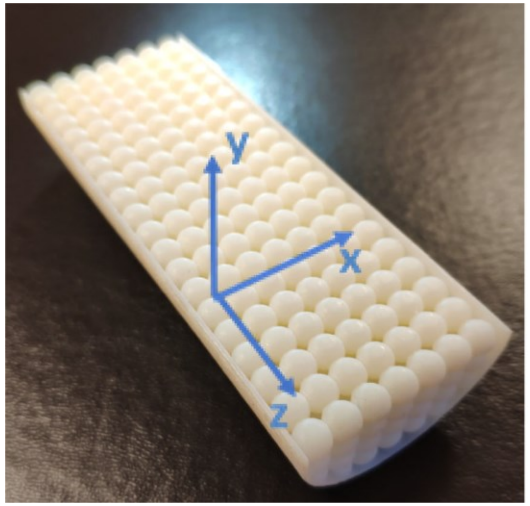
- MHD flows in capillary porous systems
- Investigation of thermoelectromagnetic phenomena in realistic liquid metal CPS

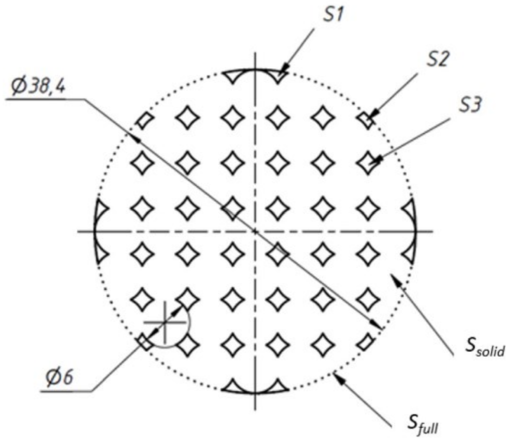
Publications and conferences in 2023:

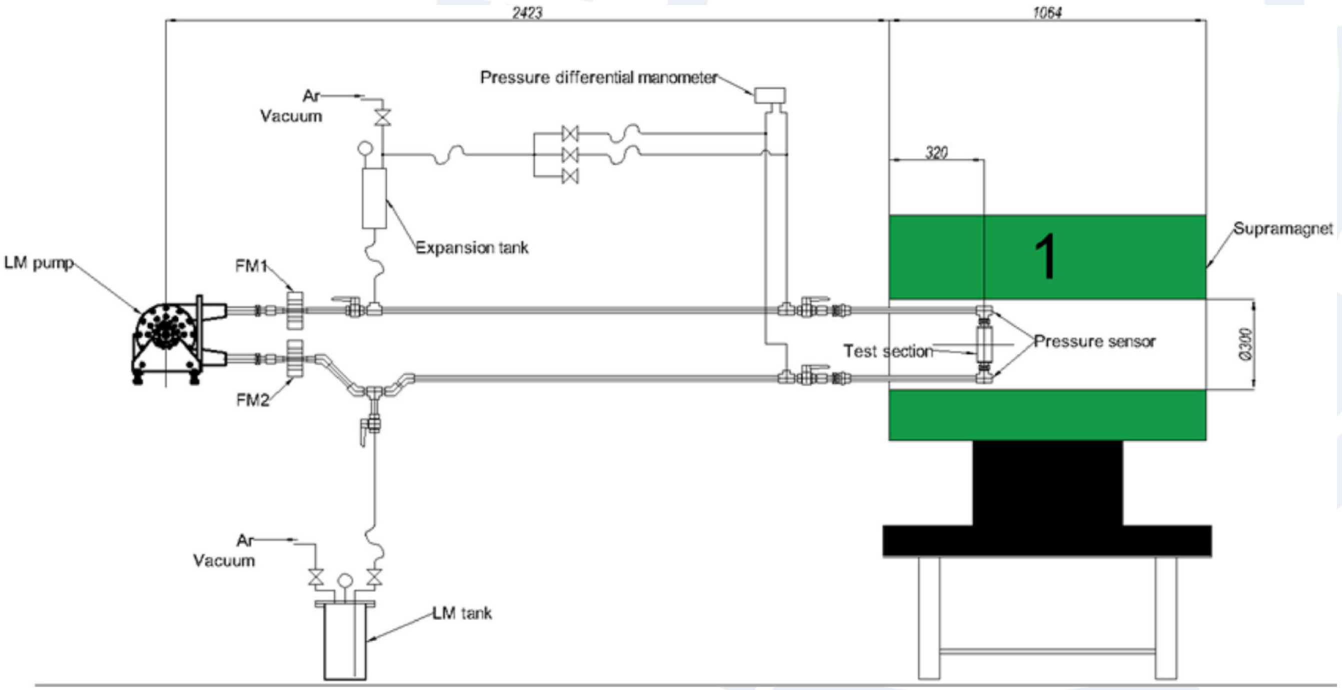
- 15th International Symposium on Fusion Nuclear Technology (ISFNT-15)
- IX International Scientific Colloquium Modelling for Materials Processing, Rīga, September 18-19, 2023, D. Berenis, I. Grants, L. Buligins Surface deformations of liquid metal flow in porous media in external uniform magnetic field. (Accepted publication in Magnetohydrodynamics)
- 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

MHD flow in capillary porous systems

3D printed capillary porous system is prepared and it is tested in high magnetic field in electromagnet and the superconducting magnet measuring the pressure drop and flow rate depending on the magnetic field direction and strengths. For better understanding of the physics the process is numerically simulated and compared with previous analytical models. It is found out that magnetic field can significantly affect the pressure flow rate behavior.

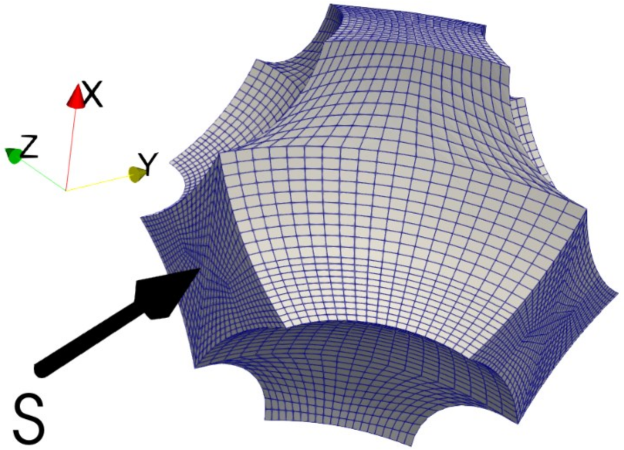


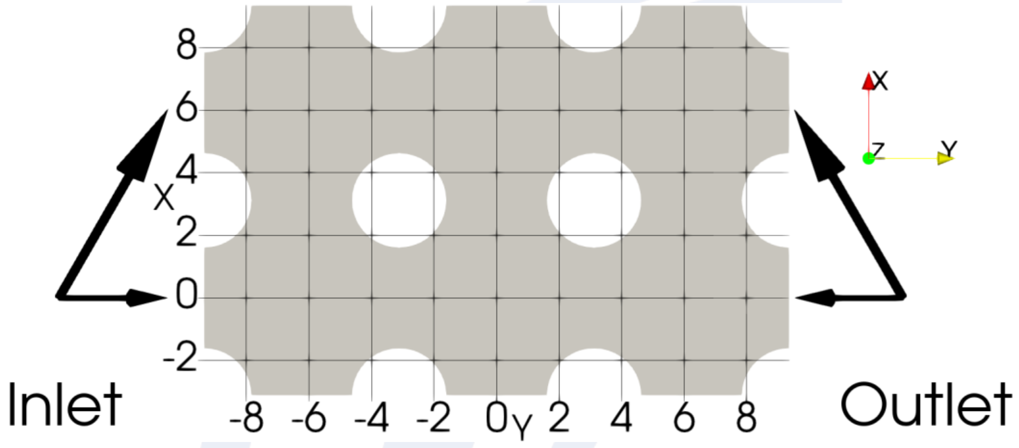




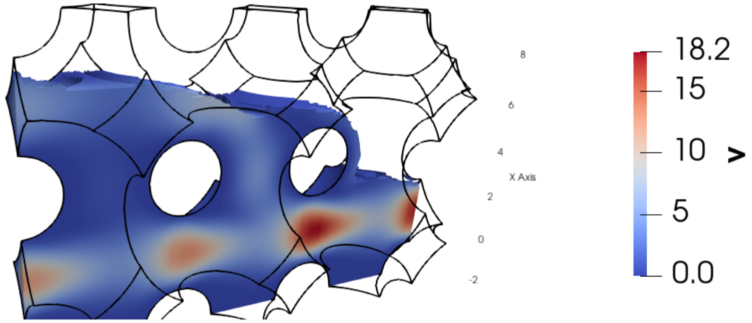
MHD flow in capillary porous systems: Numerical simulation

Characteristic length $= 0.5\sqrt{S}$

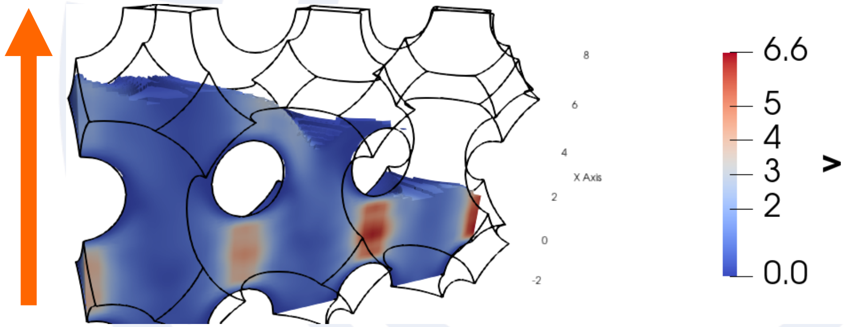




$\mathrm{B} = 0\mathrm{T}$



$\mathrm{B}_x = 4\mathrm{T}$



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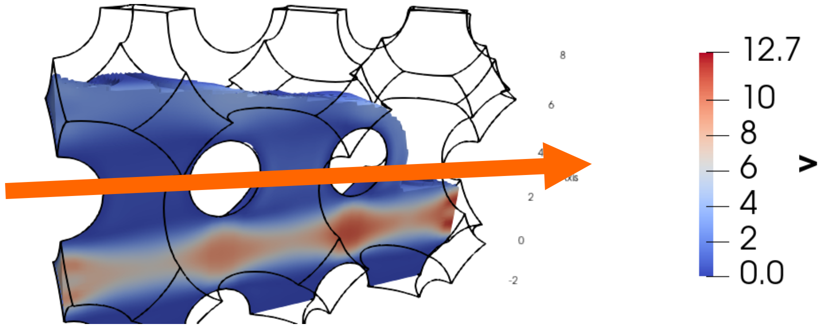
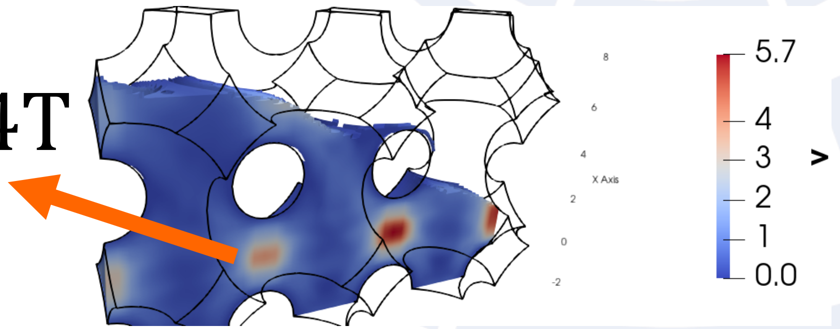
$\mathrm{B}_y = 4\mathrm{T}$



$\mathrm{B}_z = 4\mathrm{T}$

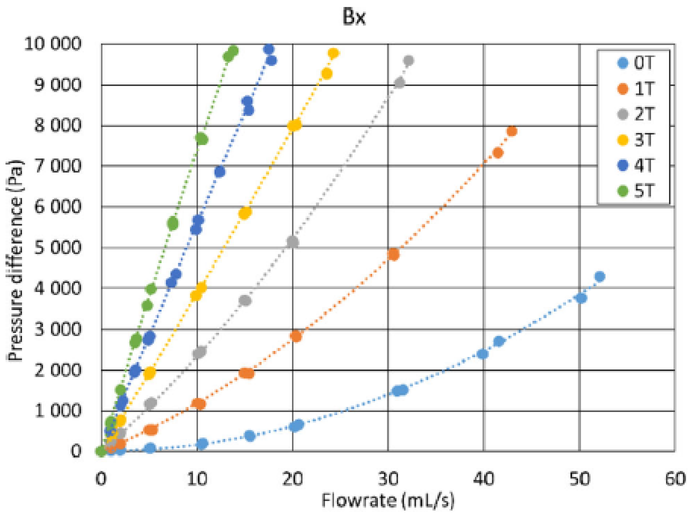


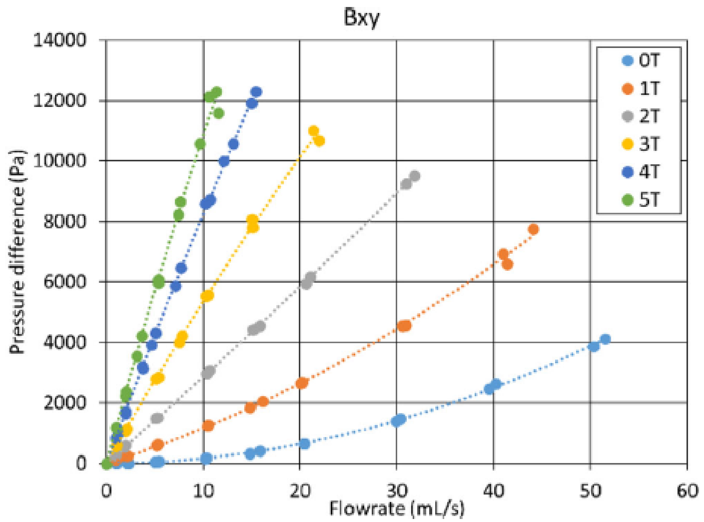
Pressure-Flowrate relation in high magnetic field

$$Re = \frac{Inertial\ forces}{Viscous\ forces} = \frac{U_0 L}{\upsilon}$$ - Reynolds number,

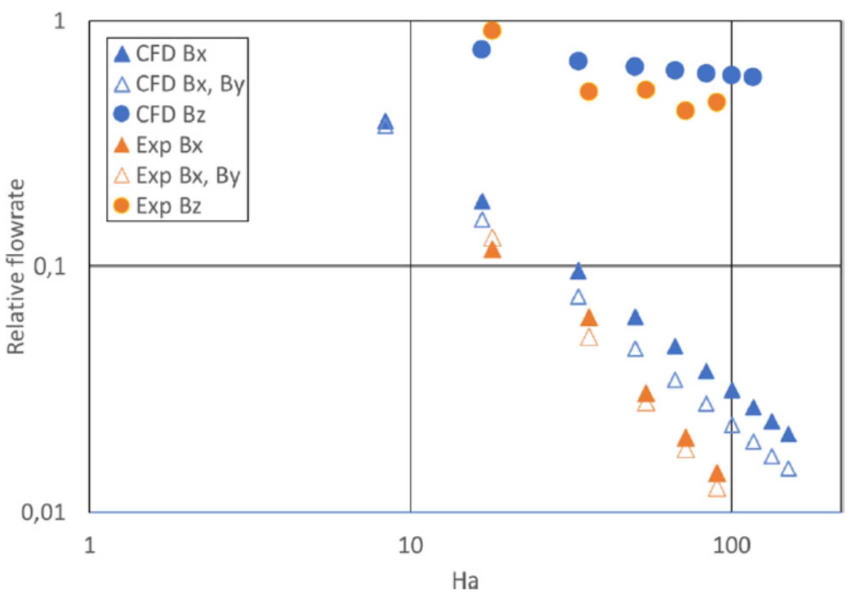
$$Ha = \left(\frac{Electromagnetic\ forces}{Viscous\ forces}\right)^{1/2} = B_0 L \sqrt{\frac{\sigma}{\mu}}$$ - Hartmann number,

$$N = \frac{Electromagnetic\ forces}{Inertia\ forces} = \frac{Ha^2}{Re} = \frac{\sigma B_0^2 L}{\rho U_0}$$ - Stuart number (interaction parameter).





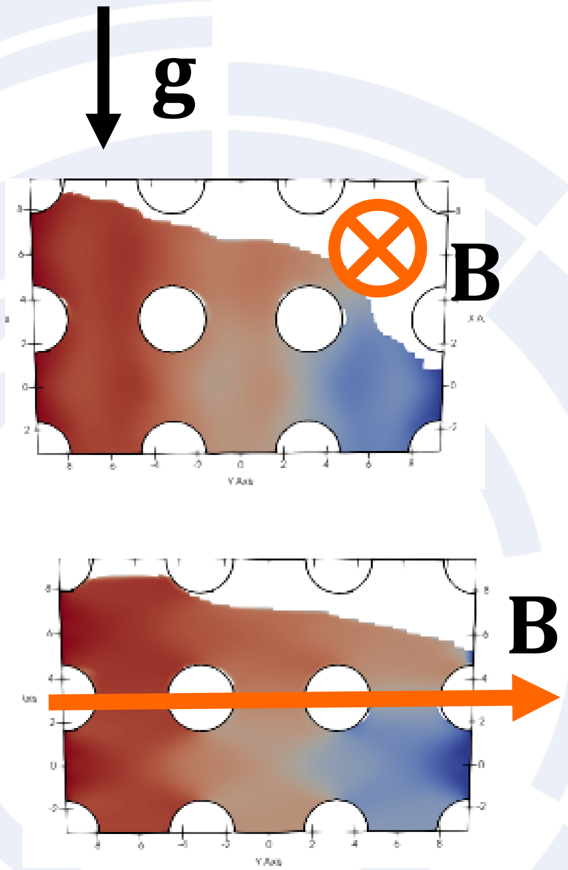
Experimental P-Q curves for Bx and Bxy orientation of magnetic field for electrically non-conducting spheres



Experiment vs. calculations for relative flowrate (ratio of flowrate at specific magnetic field and that without magnetic field) in case of electrically non-conducting spheres. Each point in graph represents one calculation or measurement. CFD – simulations, Experimental data

MHD flow in capillary porous systems: Conclusions

- Two-phase parametric direct numerical simulation was successfully performed for a 6 cell matrix.
- Simulation without surface tension models the liquid metal at the boiling temperature.
- When flow is applied to the cell matrix, a height difference between inlet and outlet is produced and consequently cell walls are uncovered.
- Magnetic field perpendicular to pressure drop and gravitation direction has the strongest braking effect and results in the largest height difference between inlet and outlet.
- Magnetic field parallel to the pressure drop shows slight increase the height difference.



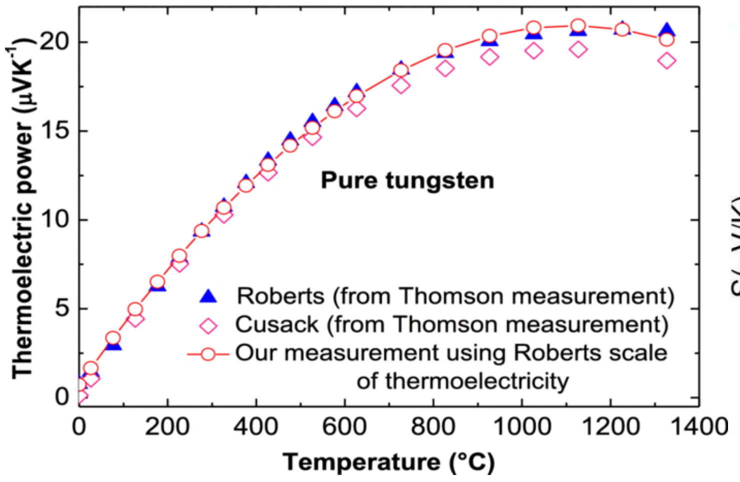
Thermoelectric phenomena may have significant effect on the liquid metal flow in magnetic field

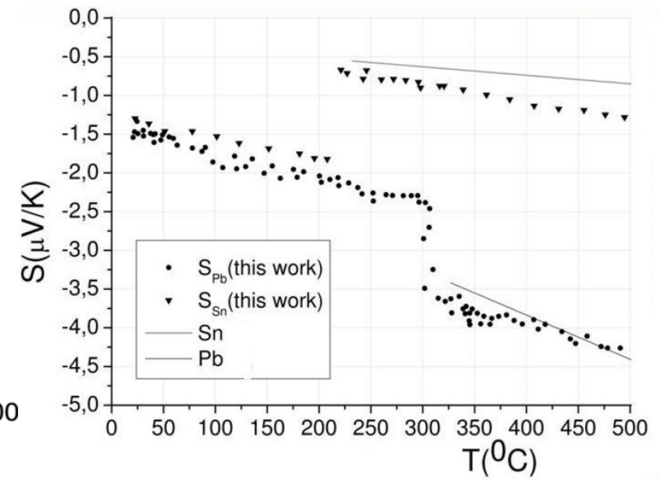
Simplified Navier-Stokes equation allows to estimate the TEMC

$$\rho \frac{u^2}{L} + \mu \frac{u}{L^2} + c\sigma\,(uB^2 - P\theta B) = 0$$

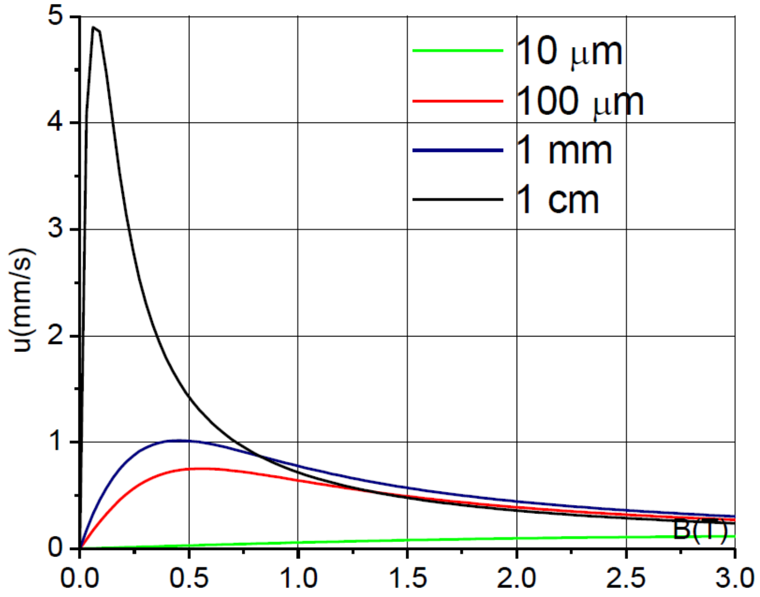
Estimation of the velocity scale from simplified equations

$$u = \sqrt{\frac{L\sigma B S \nabla T}{\rho}}$$





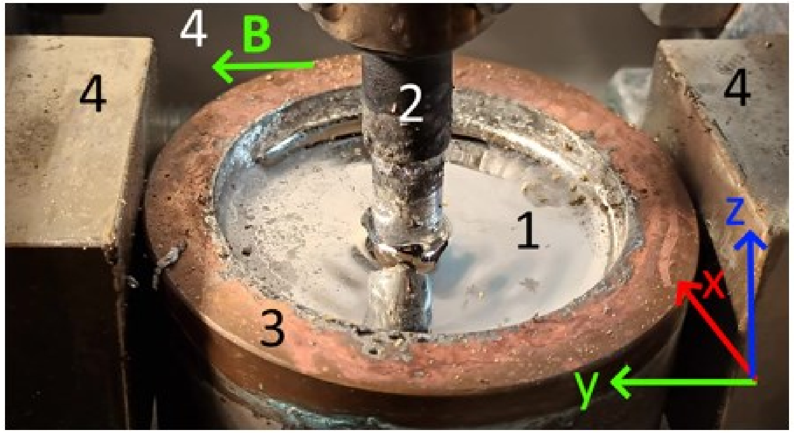
Absolute thermoelectric power off pure tungsten and the tin and lead



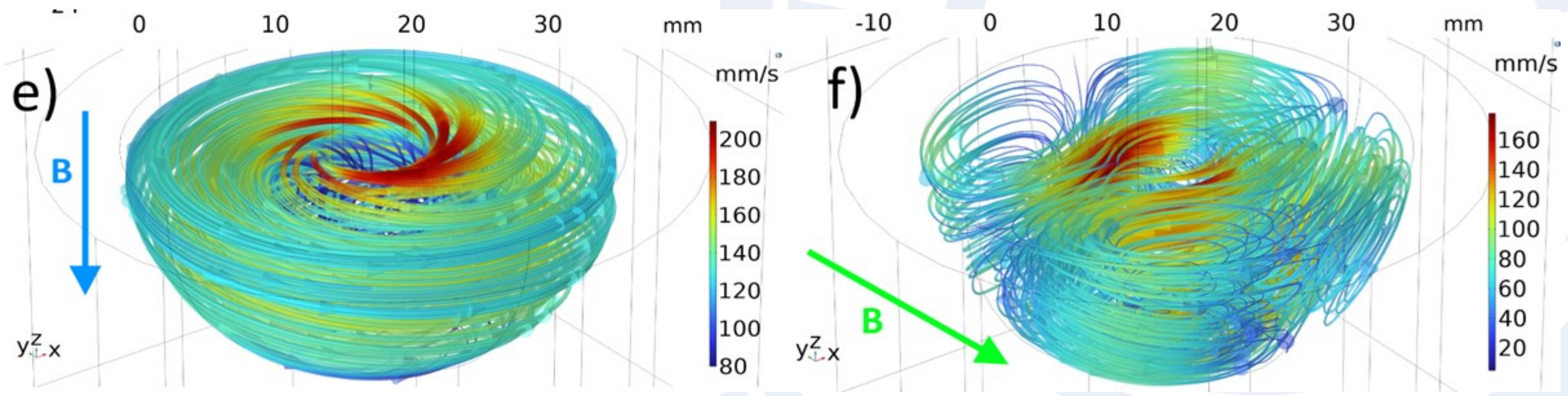
Characteristic TEMC velocities at different lengths scale. P=2 μV/K

Thermoelectromagnetic effects in capillary porous systems

Liquid metal capillary-porous system in plasma chamber is subjected to high thermal gradient and strong magnetic field, thus our calculations and preliminary experiments have demonstrated that thermoelectromagnetic effect can be significant. We have done numerical calculations, showing the force density in the liquid metal, which can exceed any other force acting on it, and also we have done series of experiments in different geometries showing that thermoelectromagnetic convection can drive significant liquid metal flow in small scale.

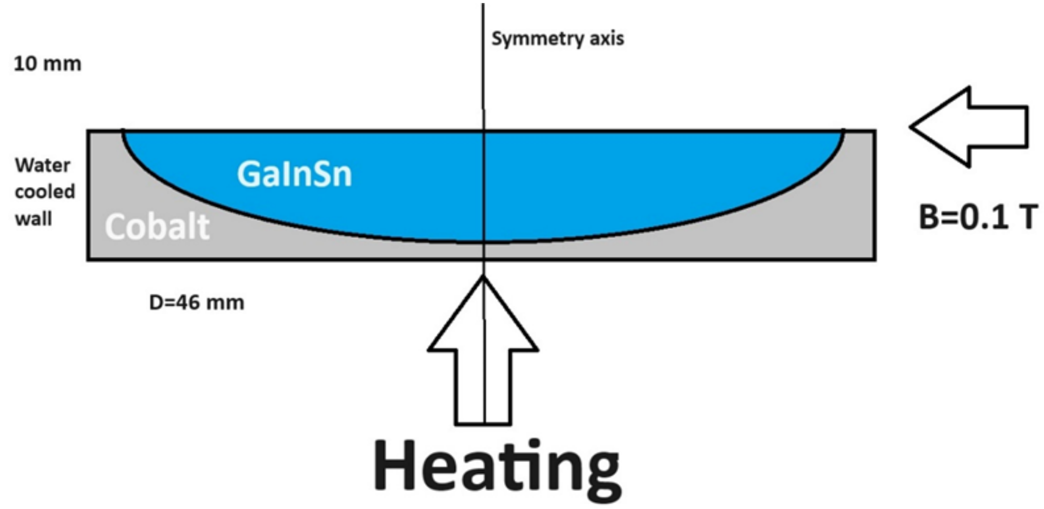


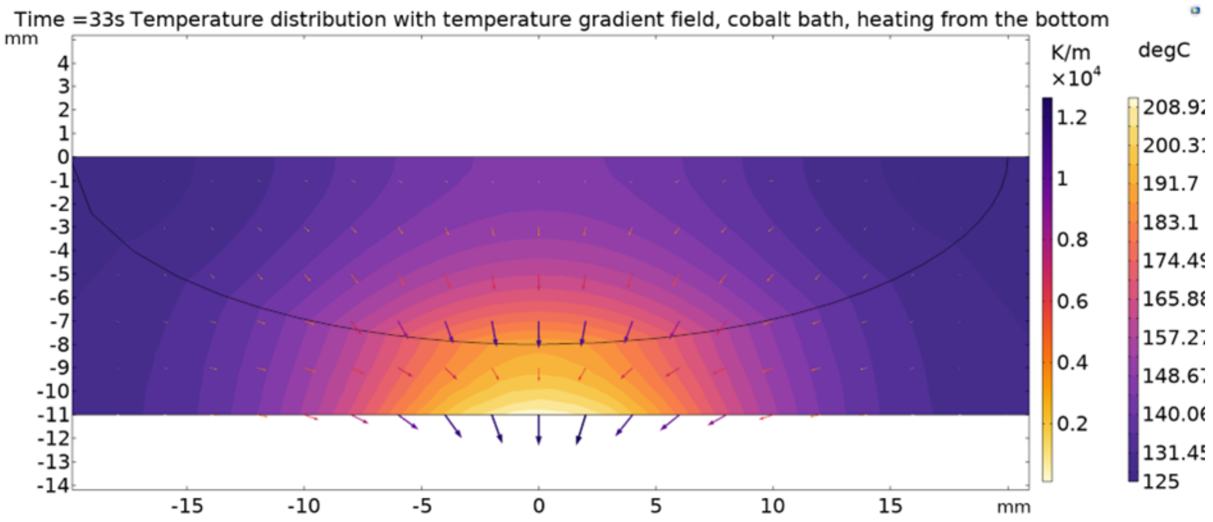
Liquid metal pool experiment. 1-GaInSn, 2-Cobalt rod, 3-Copper, 4-Permanent magnets

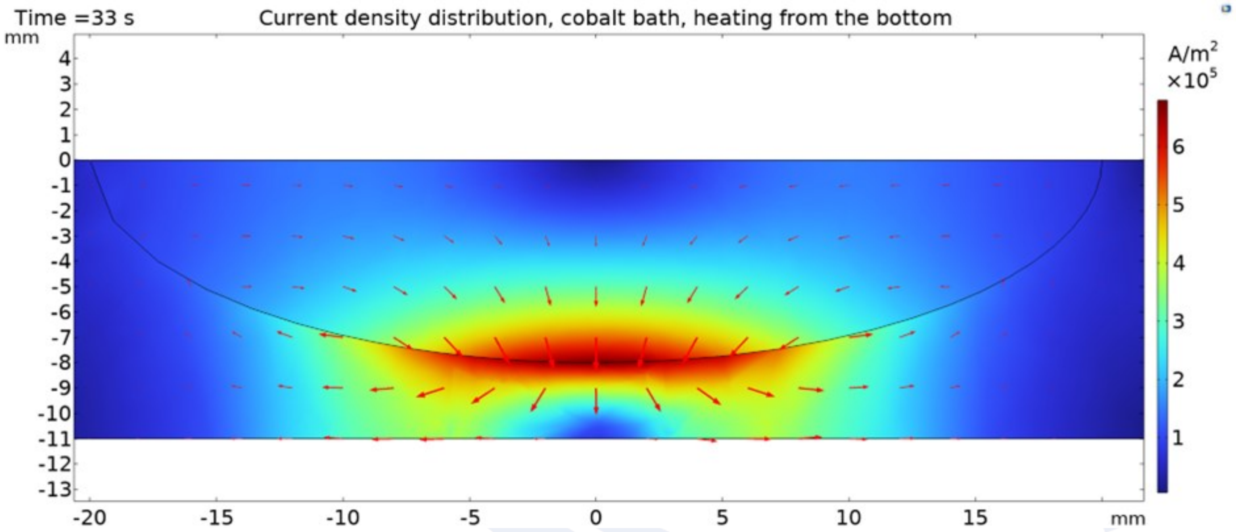


Liquid metal experiment and numerically calculated velocity distribution in liquid metal with applied axial and transient magnetic field of 0.2 Tesla. Agreement between numerical modeling and actual surface observation measurements is good.

Experiment to quantify TEMC in GaInSn/Co system

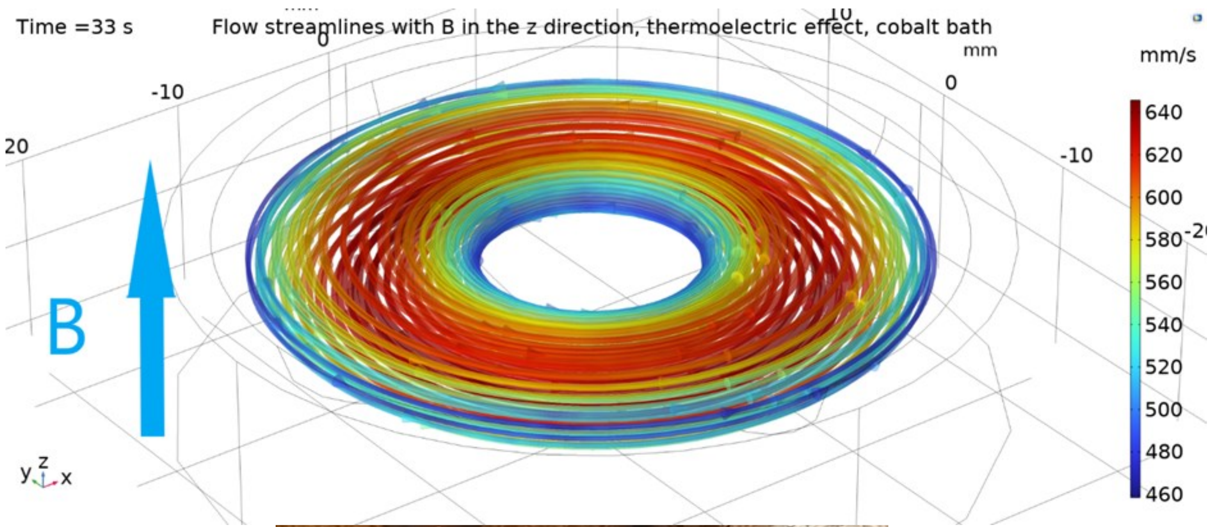


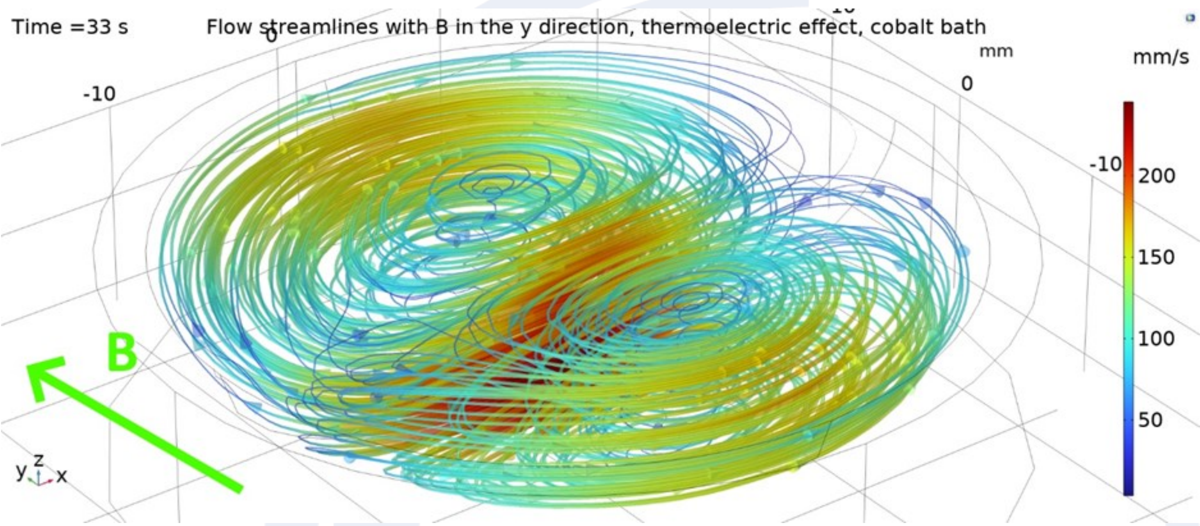




Numerically simulated temperature distribution and current distribution in the cobalt bowl field with GaInSn

Comparison of numerical models and experiment





Relevant dimensionless numbers and equations

For numerical simulation of the process we use non-compressible flow approximation, heat transfer equation and Ohms law with Seebeck term for calculation of electromagnetic problem.

$$\rho(\boldsymbol{u}\cdot\boldsymbol{\nabla})\boldsymbol{u} = -\boldsymbol{\nabla}\boldsymbol{p} + \mu\nabla^2\boldsymbol{u} + \overbrace{\boldsymbol{J}\times\boldsymbol{B}}^{Lorentz\ force} + \boldsymbol{f}$$

$$\overbrace{\rho c\boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{T}}^{Convection} + \overbrace{\boldsymbol{\nabla}\cdot(-k\boldsymbol{\nabla}\boldsymbol{T})}^{Conduction} = \overbrace{q}^{Source}$$

$$\frac{\boldsymbol{J}}{\sigma} = \boldsymbol{E} + \boldsymbol{u}\times\boldsymbol{B} - \overbrace{S\boldsymbol{\nabla}\boldsymbol{T}}^{Seebeck\ effect}$$

- Inertial and viscous forces is characterized by Reynolds number Re
- Convective and conductive heat transfer is the Peclet number Pe
- Buoyancy and viscous force is characterized by Grasshoff number Gr
- Marangoni and viscous force is characterized by Marangoni number Ma.
- Electromagnetic and viscous forces is characterized by Hartmann number squared Ha^2.

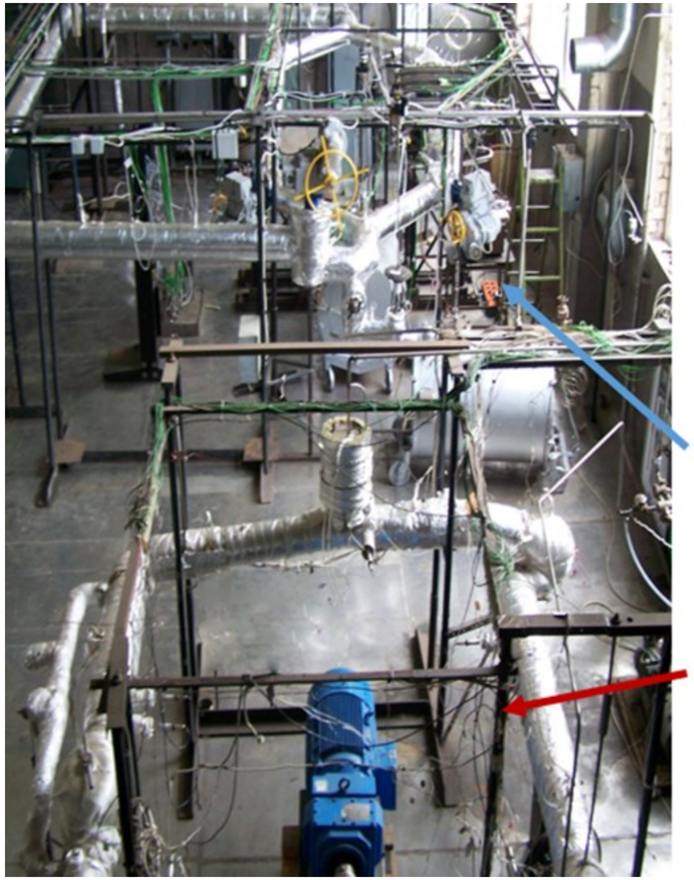
$$Re = \frac{\rho uL}{\mu} \qquad Pe = \frac{\rho cuL}{k} \qquad Gr = \frac{L^3\rho^2\beta\Delta Tg}{\mu^2} \qquad Ma = \frac{\partial\gamma}{\partial r}\frac{\rho cL\Delta T}{\mu k} \qquad Ha^2 = Re * N = \frac{\sigma B^2L^2}{\mu}$$

Plans for 2024 and beyond

In 2024 it is planned to continue the research activities in following directions:

- **Experimental and theoretical investigation of the thermoelectric phenomena** and its role into realistic conditions. It is planned to continue small scale experiments with cobalt/GaInSn system for better understanding of MHD flow and merging in different geometries. Experimental results are compared with numerical results and scheduling algorithm is developed for comparison with the processes which can take place in actual plasma facing component. It is planned to do numerical simulation and compare the results with measured liquid metal flow.
- **Analysis of the MHD flow in capillary porous systems**. It is planned to continue experimental work with various 3D printed capillary porous systems and investigation of their behavior under strong magnetic field. Results will be compared with numerical models and scaled force the processes in plasma chamber.

IPUL liquid metal laboratory and journal «Magnetohydrodynamics»



Special 240 m^2 experimental hall:

Coated with stainless steel (floor and walls)

Sodium (Na) loop

Lead – Bismuth (PbBi) loop

https://mhd.sal.lv/