EUROfusion

WPLMD 2022:

Magnetohydrodynamic flow in CPS, Thermoelectromagnetic effects in liquid metal CPS

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Institute of Physics University of Latvia (IPUL) specializes in Magnetohydrodynamics research

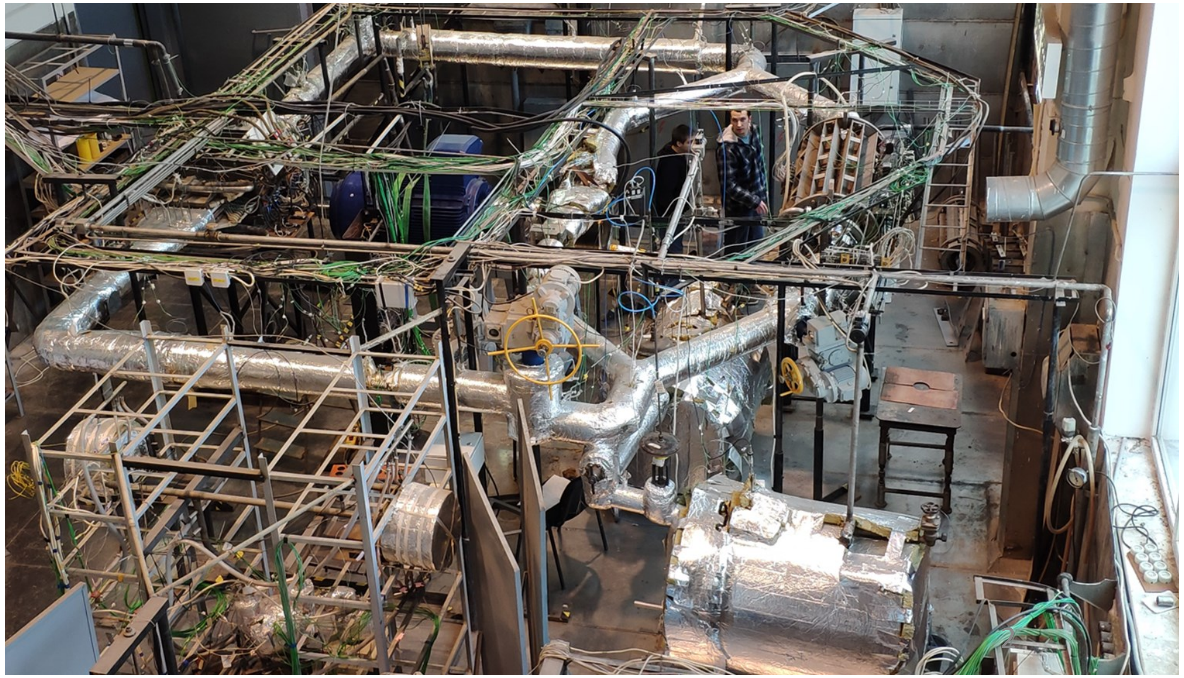
IPUL main work in Eurofusion program

*Evaluation of thermoelectromagnetic effect in liquid metal CPS
*Investigation of MHD flows in capillary porous systems

IPUL designed and produced permanent magnet induction pump

Liquid metal: Pb-Li
ΔP_{max}=6.5 bar
Q_{max}=1.7 l/s
T_{max}=350° C

IPUL alkali metal hall with 125 mm diameter Sodium loop



Outlook for the IPUL tasks in 2022

Electric current effects on LM flow

Work in 2022 :

- Experiments with different current values and orientation and magnetic field 0-5T
- Measured values: flowrate, pressure difference and magnetic field
- Free surface visualisation

Thermoelectric effect quantification

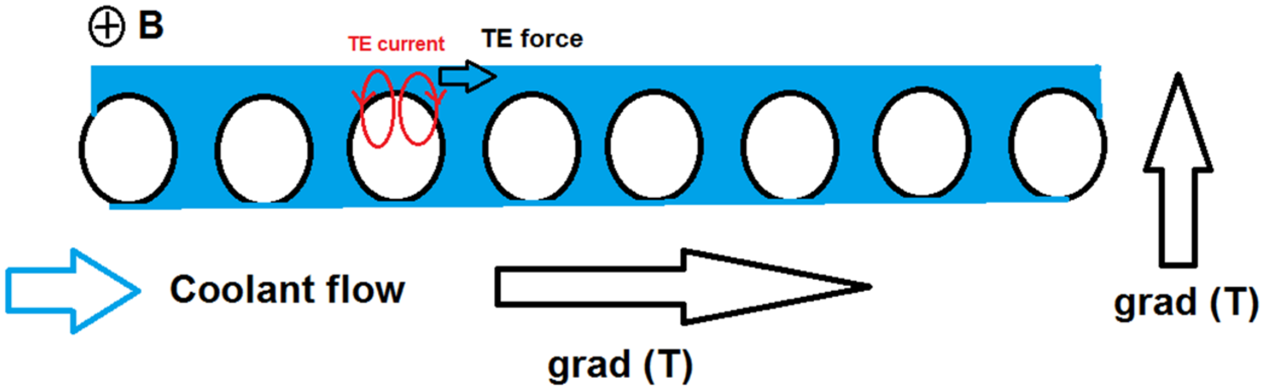
-Experimental study of thermoelectromagnetic effect in Co-GaSnIn system(measure temperature distribution and liquid metal flow)

-Complete numerical model (Electric current, temperature, flow and surface deformation)

-Analythical description and similarity with realistic W-Sn system

Themoelectric (TE) effect in divertor CPS

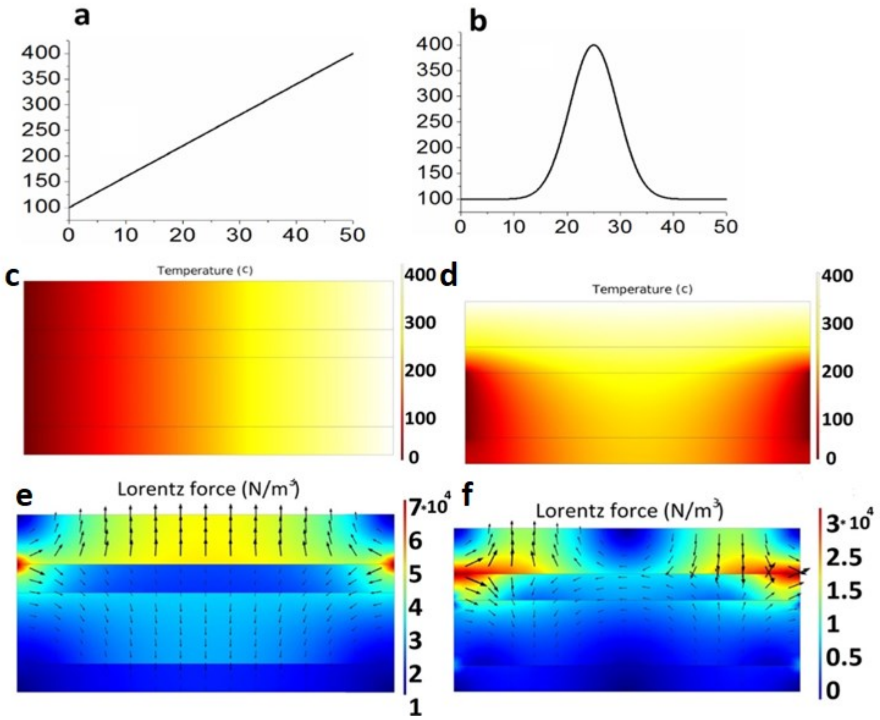
- W and liquid Sn CPS system, TE force may appear at the nonisothermal interface between solid and liquid phases
- Calibration experiment is developed to quantify the thermoelectromagnetic convection in liquid metals in small scale.



Comparison of characteristic values of model and CPS:
Cobalt-Gallium (ΔS=30 μV/K, σ=2 MS/m, θ=3 K/mm, B=0.2 T
Tungsten-Tin (ΔS=10 μV/K, σ=2 MS/m, θ=10…100 K/mm, B=1..5 T)

F~σ·ΔS·θ·B

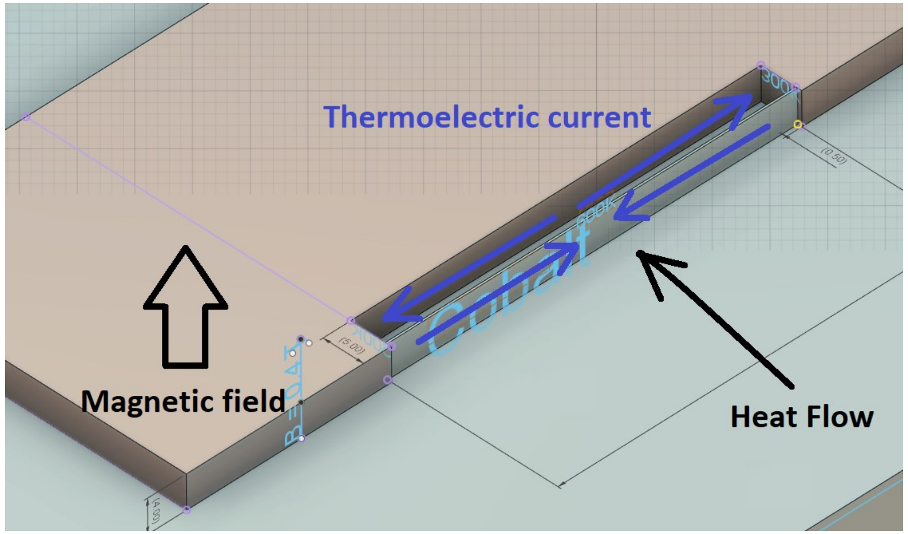
Local Thermoelectric force can be higher than in experiment. It is shown that TE force will push the liquid metal away from the hottest zone.



Thermoelectric current density if nonhomogeneous heat flux is applied. a, b-temperature profiles along plasma/CPS surface, c,d-temperature profile, e,f-calculated thermoelectric force density. F=30kN/m^3 is larger than gravity Fg=ρg=6kN/m^3

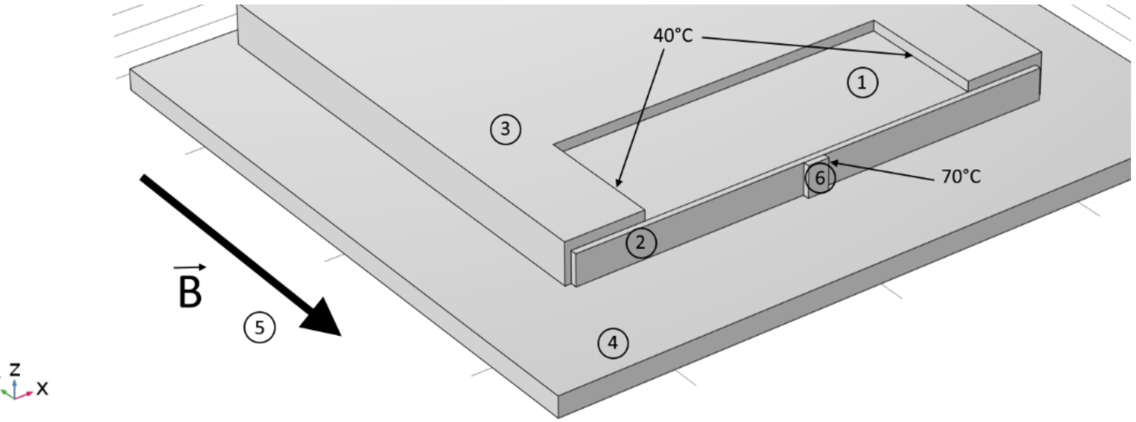
Planned experiment

- S_{Co}=-20 μV/K, S_{ga}=-0.3 μV/K, ΔT=200 K, L=4 cm, B=0.5 T, σ_{Co}= 15 MS/m, σ_{Ga}=2 MS/m
- TE voltage $U=\Delta S\cdot\Delta T$=1e-3 V Current density: $j=U\sigma/L$=2e5 A/m^2
- TE force density: $f=j\times B$=1e5 N/m^3 Gravity: $f_{Ga}=\rho_{Ga}g$=7e4 N/m^3
- This simple order of magnitude estimation shows that even with low magnetic field and moderate thermal gradient it is possible to achieve force density larger than gravity. This experiment would allow to verify how the liquid metal is pushed away from the hot zone by thermoelectric forces and compare the result with numerical models and analytical calculation.



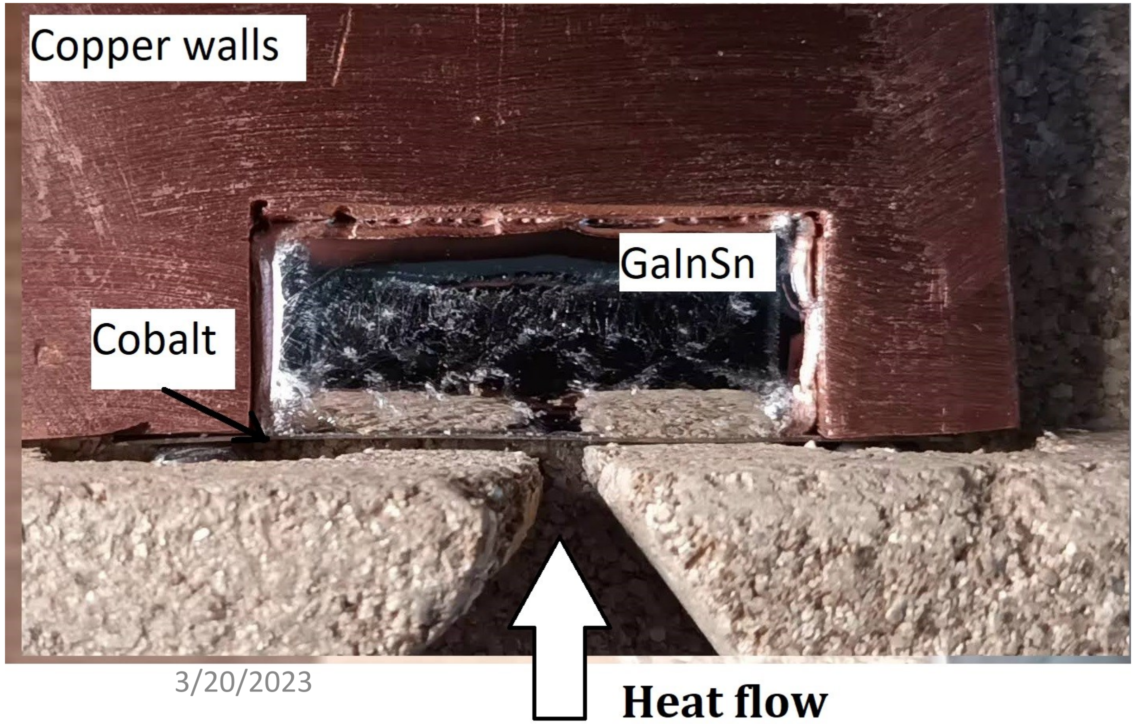
Numerical model confirms the analythical calculations.

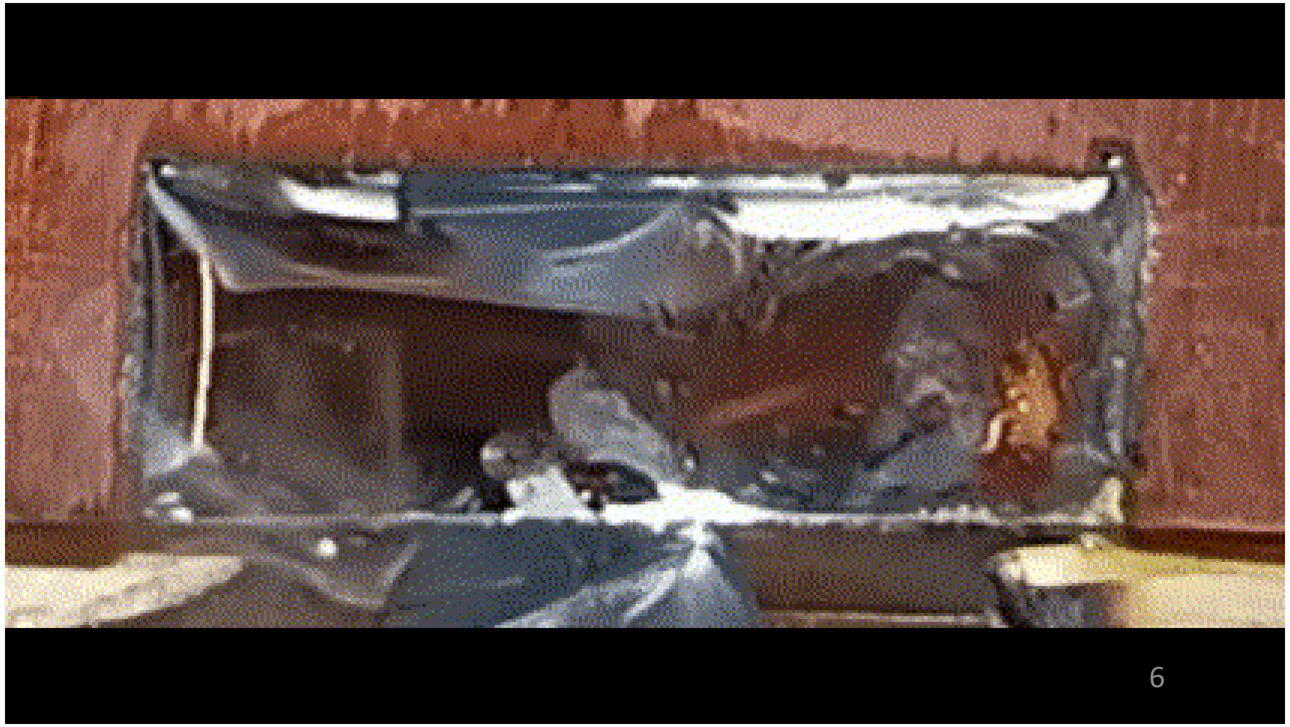
Thermoelectric magnetic flow experiment for liquid metal divertor studies



Liquid metal (InGaSn) container has three cooled copper walls and one cobalt wall. Along the cobalt wall temperature profile is imposed by electric heater. External magnetic field B=0.2 T is applied by permanent magnet assembly.

$$\vec{v} = 7.4 \pm 1.2 \frac{cm}{s}$$



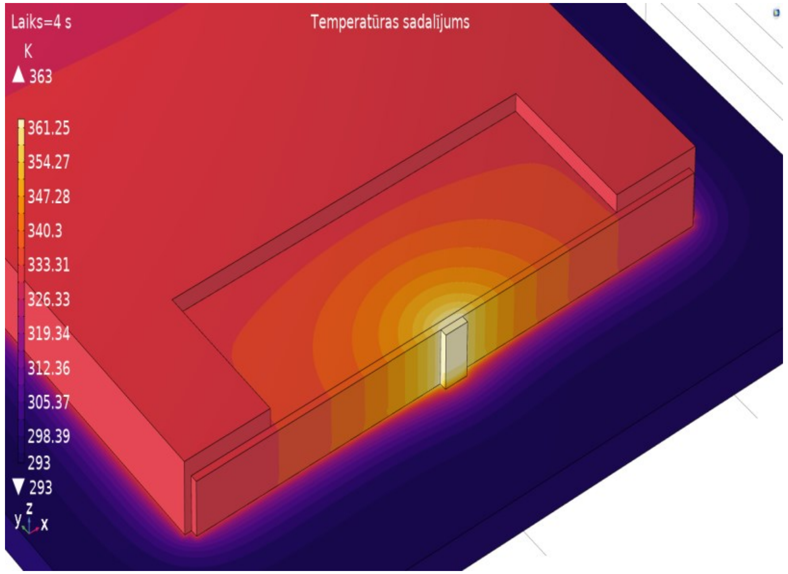


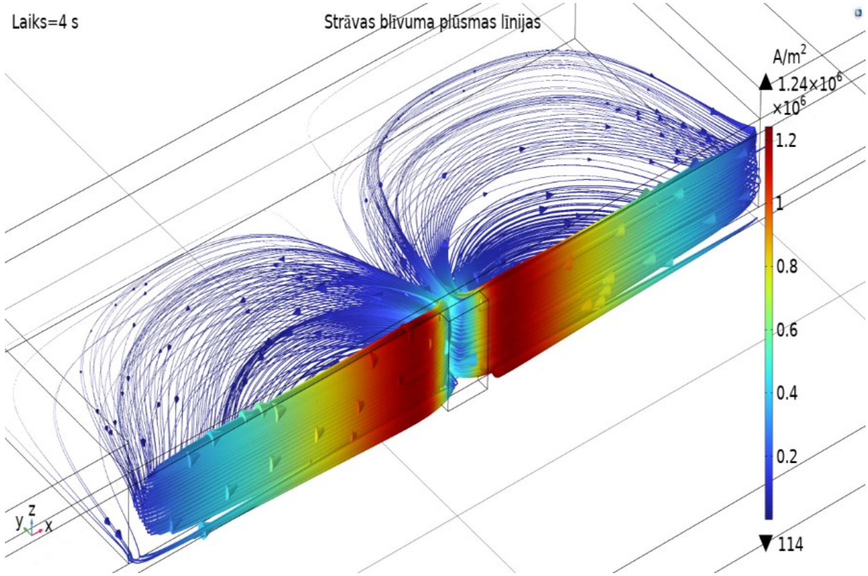
Numerical simulation results

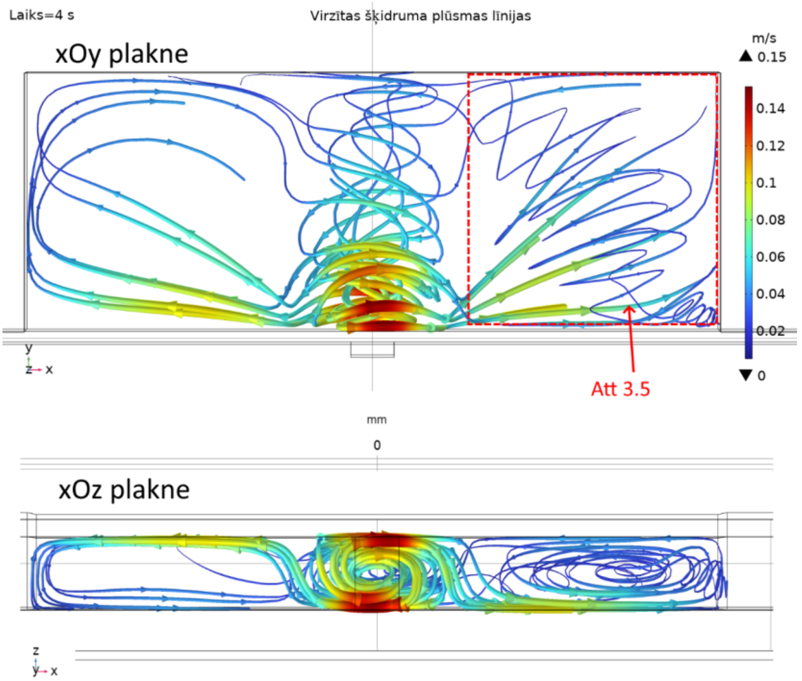
Temperature distributiion

Thermoelectric current distribution

Fluid flow







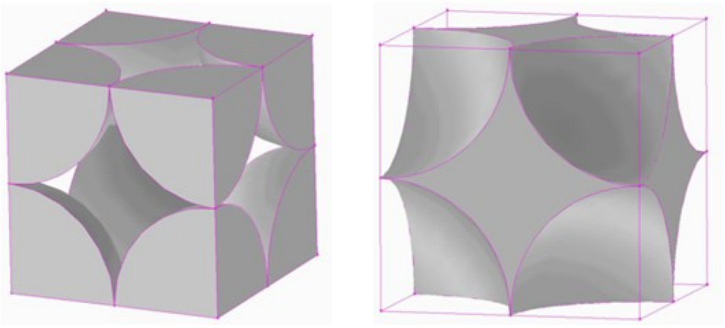
Main dimensionless numbers

$$Re \sim 2220, Pe_L \sim 6, N \sim 26, \vec{v} = \sim 3 - 5\,\frac{cm}{s}$$

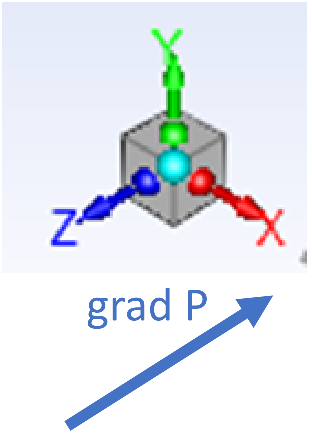
$$Re = \frac{\rho u L}{\mu}\,(Inertia/viscous),\;\; Pe_L = \frac{Lu}{(\frac{k}{\rho C_p})}\,(conduction/convection),$$

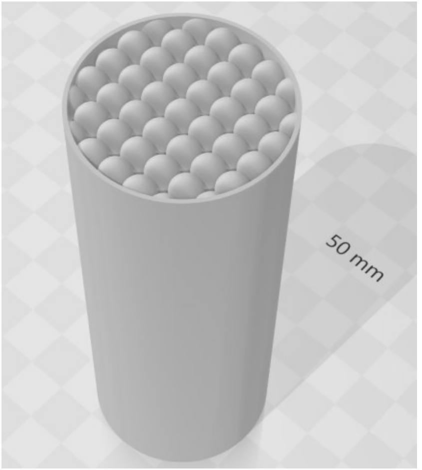
$$N = \frac{B^2 L \sigma}{\rho u}\,(Electromagnetic/inertia)$$

MHD flow in porous media



SC pore model – solid matrix and pore space 1 unit size cube

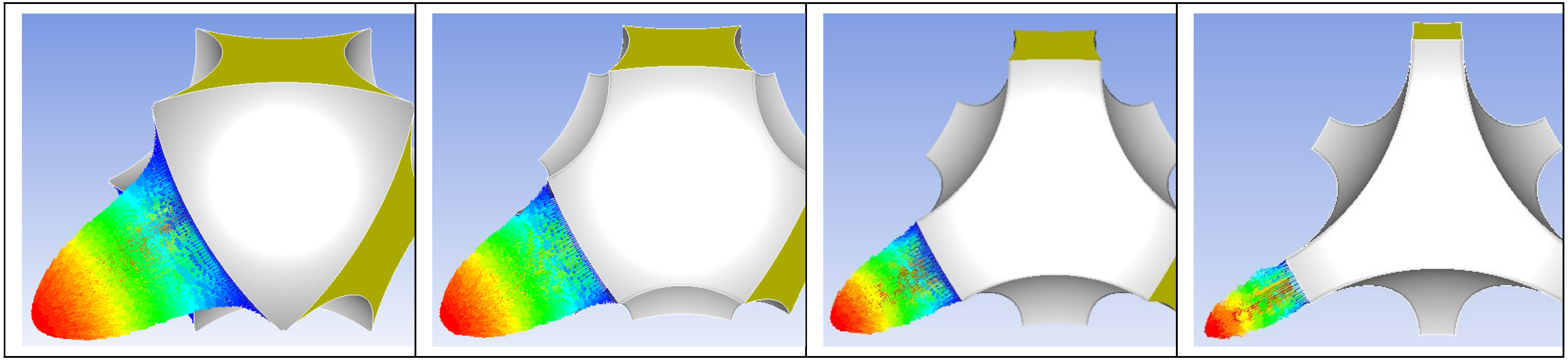




Experiments with 3D printed non-conductive test section with InGaSn in magnetic field up to 5T.

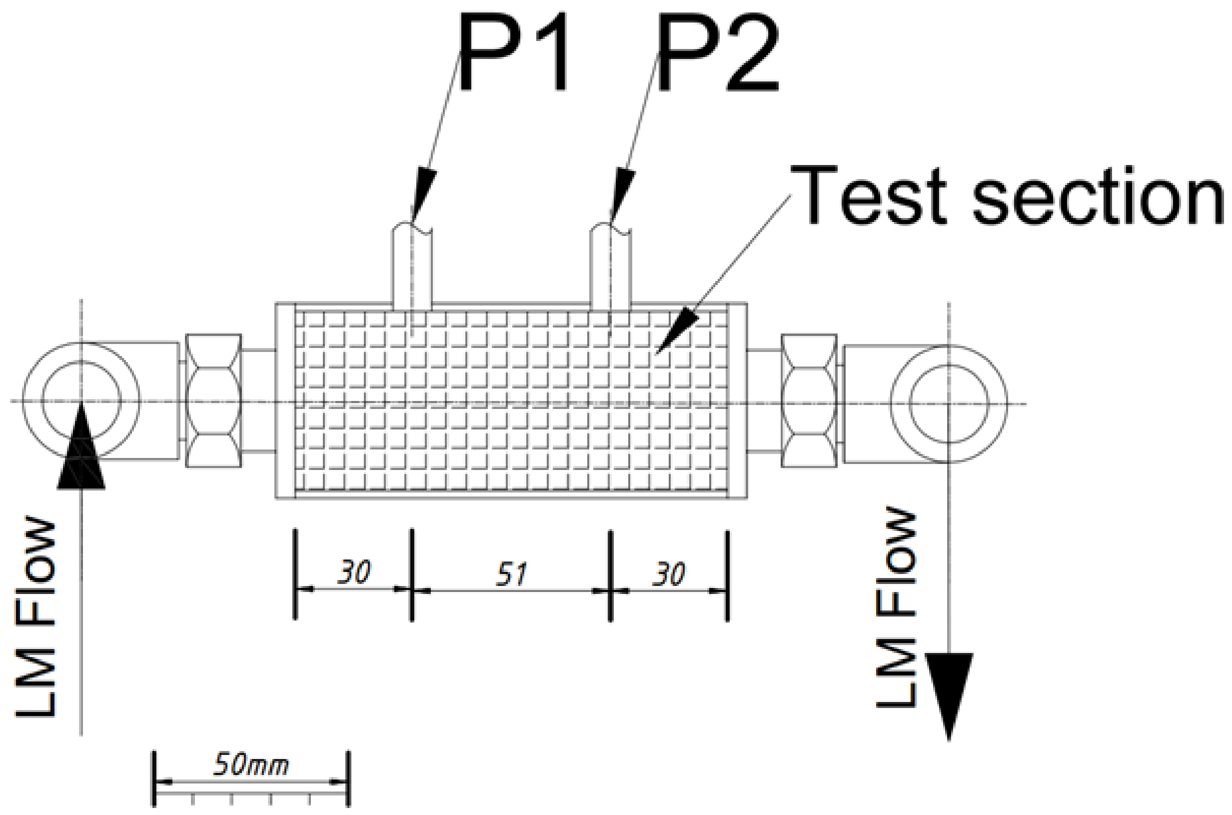
Simulations with ANSYS Fluent with MHD module Potential formulation, models with ideally conductive and non-conductive solid matrix, *Re*=0.01<<1.

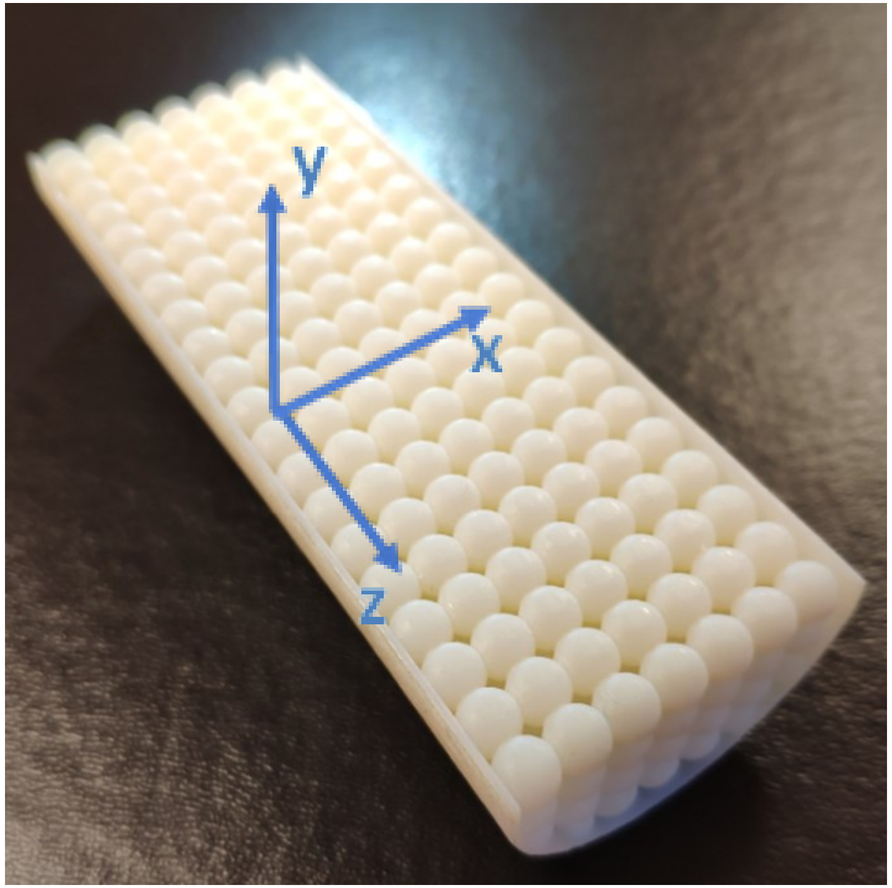
Overlaping (1/10) sphere model



R=0.5 R=0.55 R=0.6 R=0.65

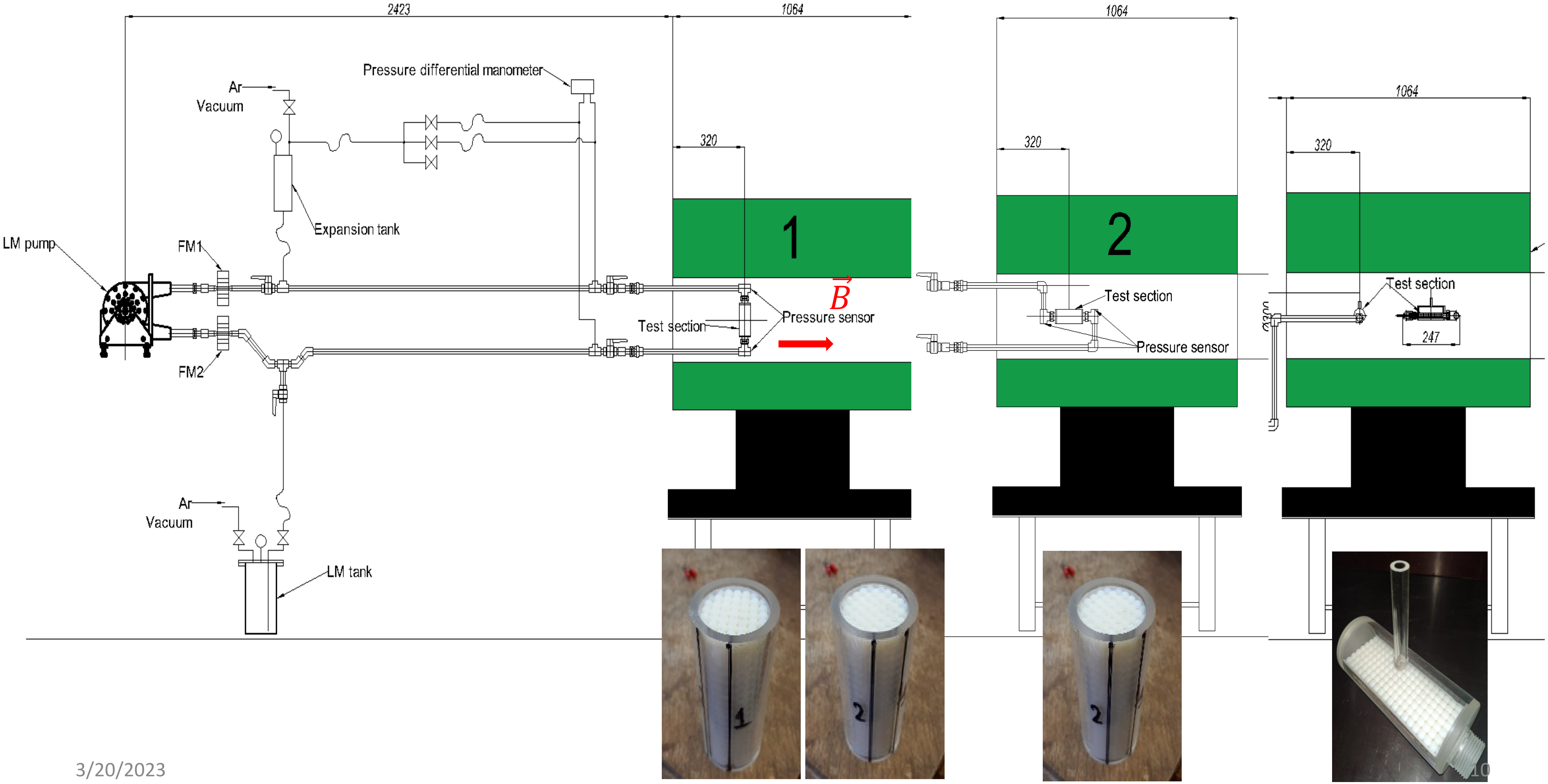
Test section (3D plinted non-conductive, R=6 mm)



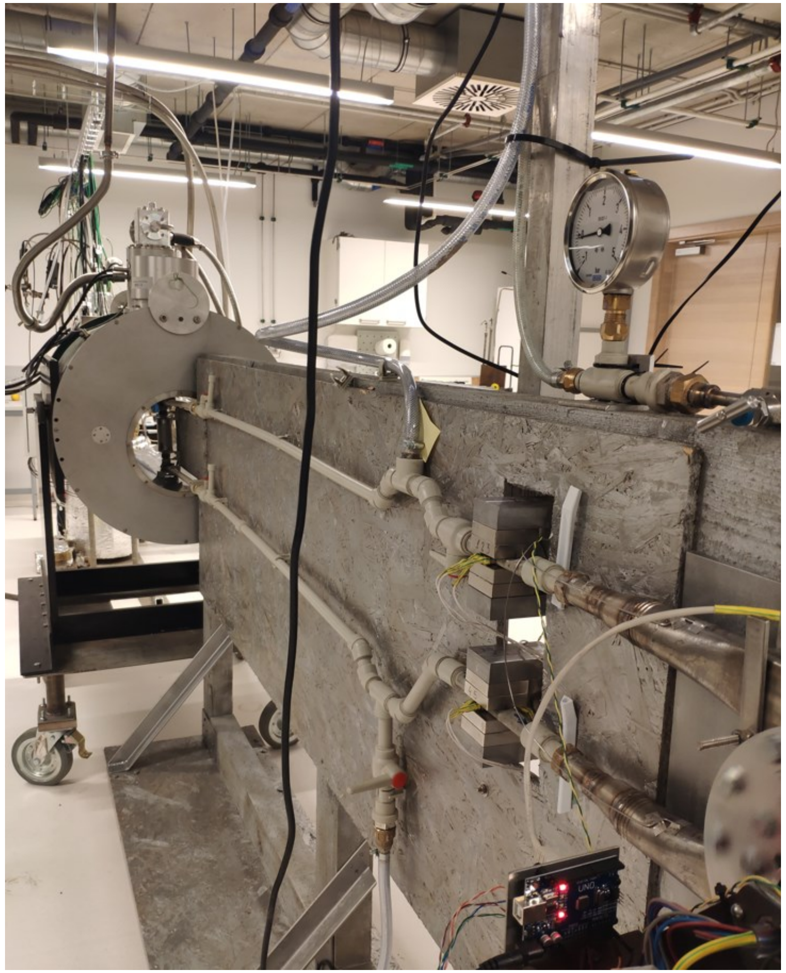


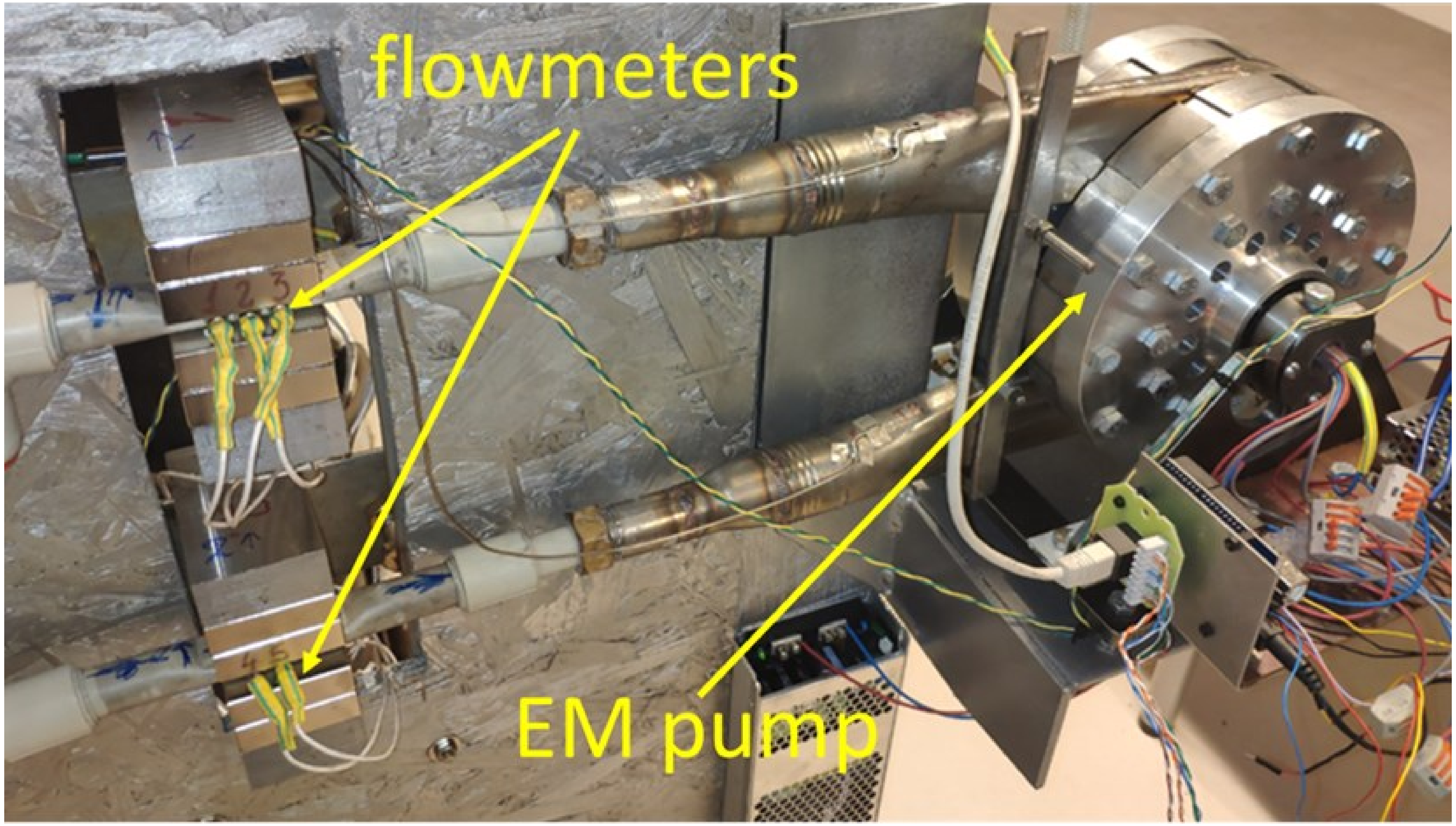
P1, P2-pressure sensors, Flowrate sensors, can be placed in supermagnet (0-5 T)

Experimental setup

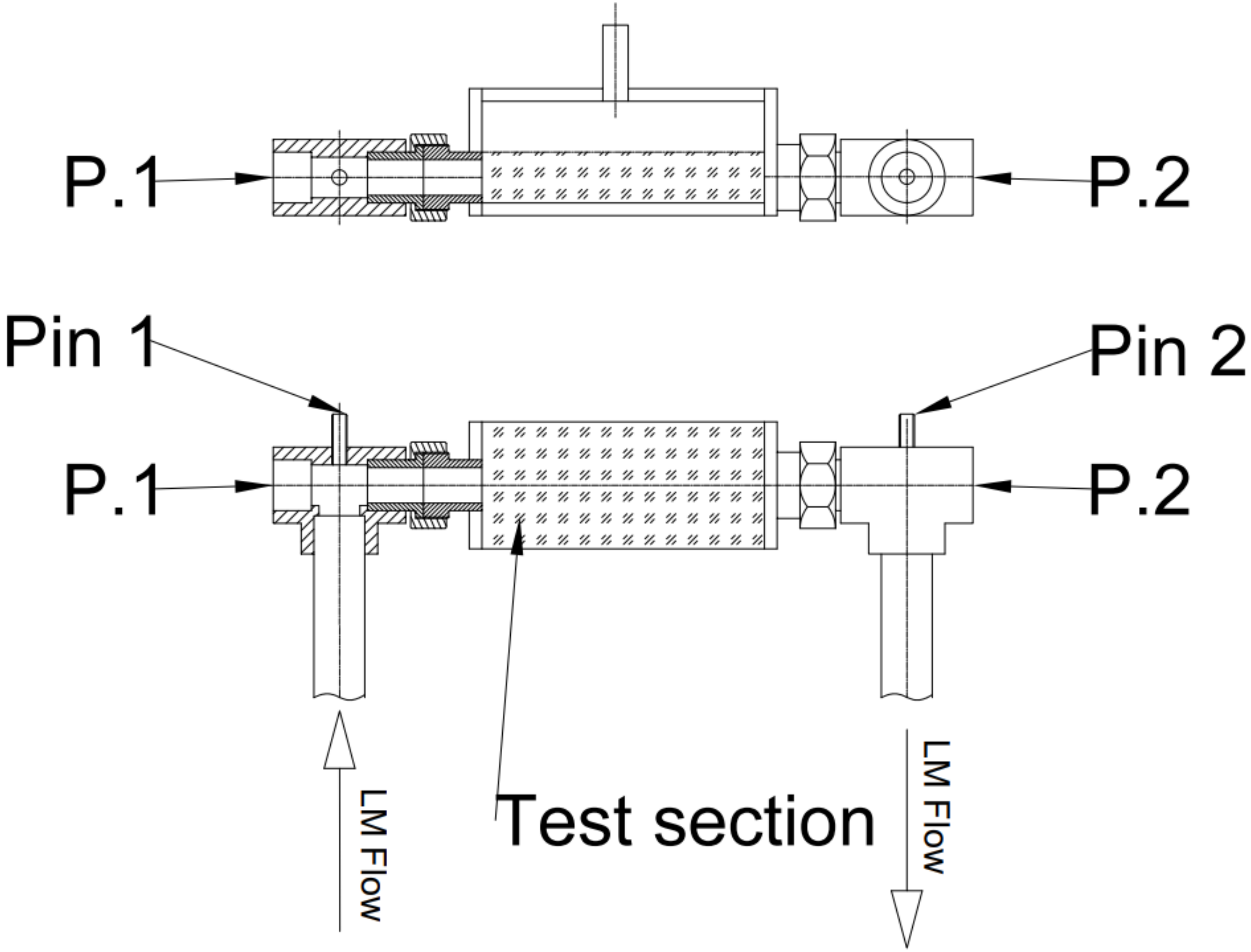


Experimental setup





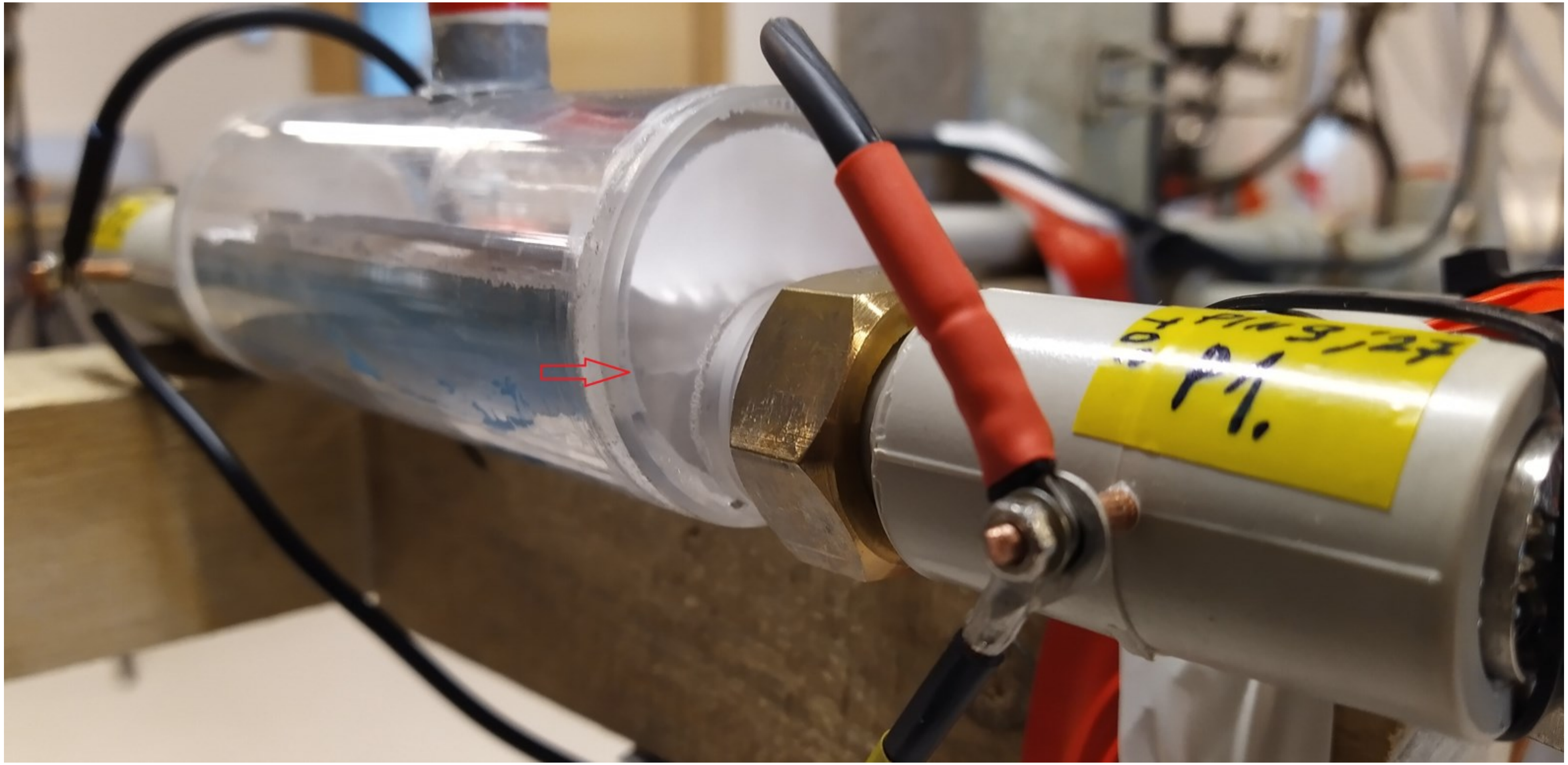
Electric current effects on LM flow



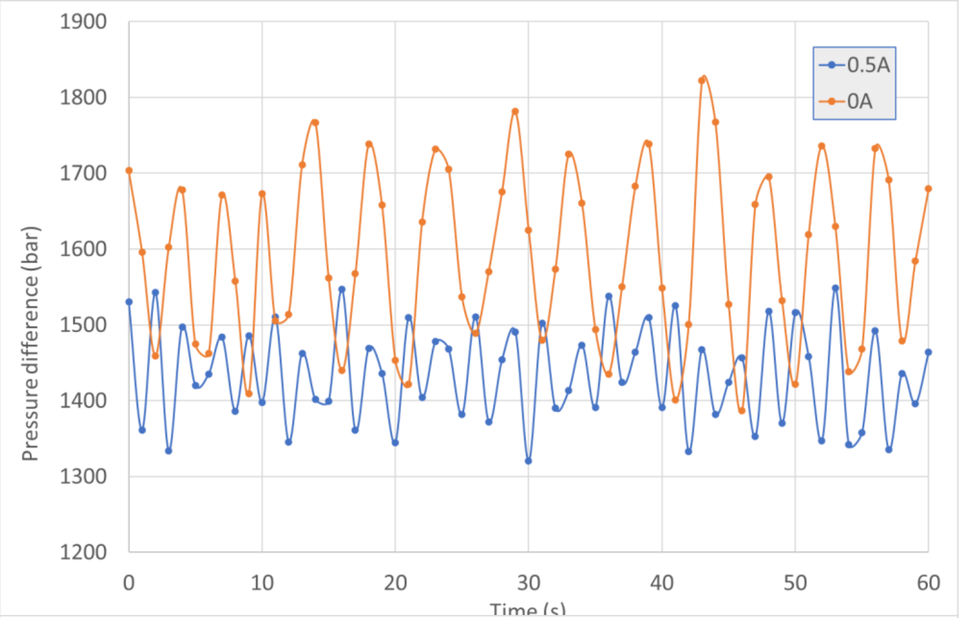
Work in 2022 :

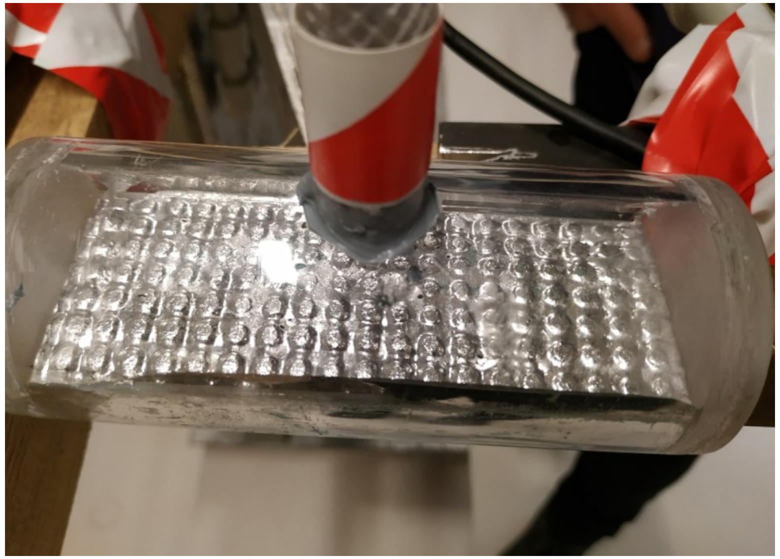
- Test section upgrade with pins for applying electric current
- Incorporating current source
- Modifying liquid metal loop
- Implementing new adata channels in NI system
- Updating LabView software
- Preliminary experiments

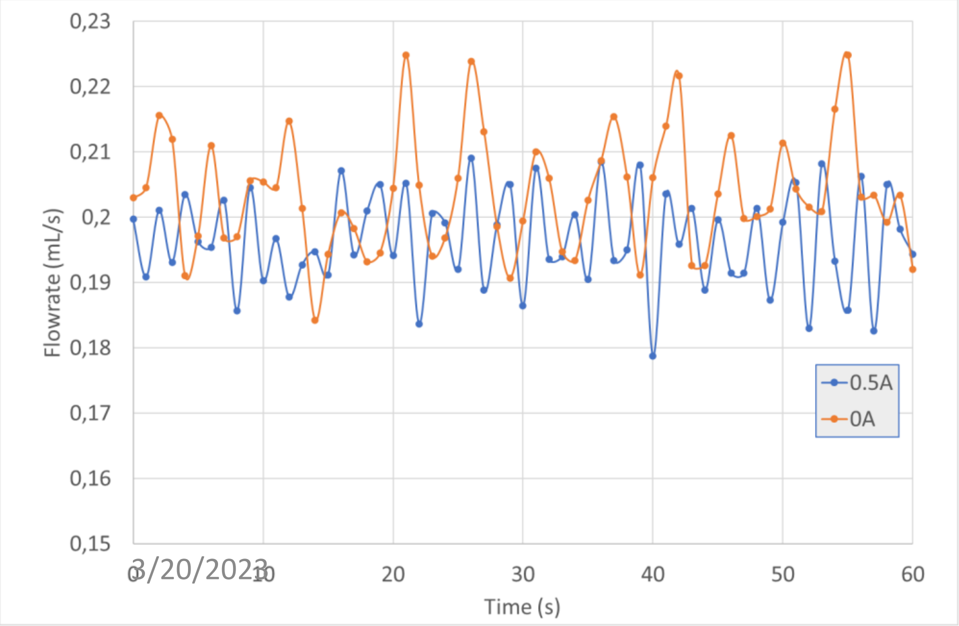
Test section (TS) with current electrodes



Experiments at B=2T to study jxB influence on the flow

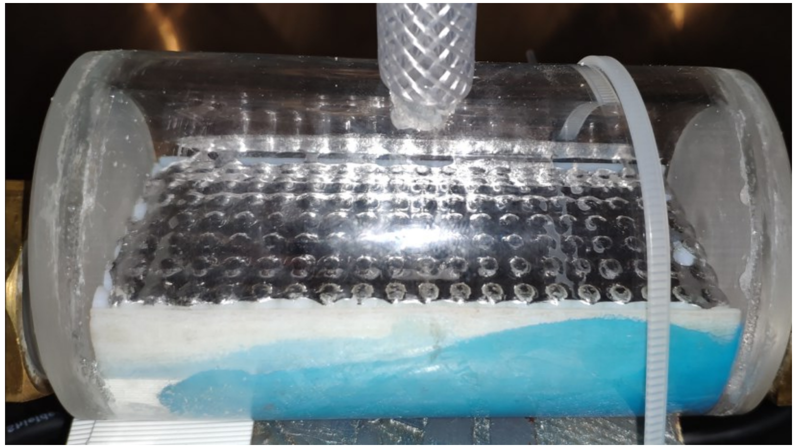




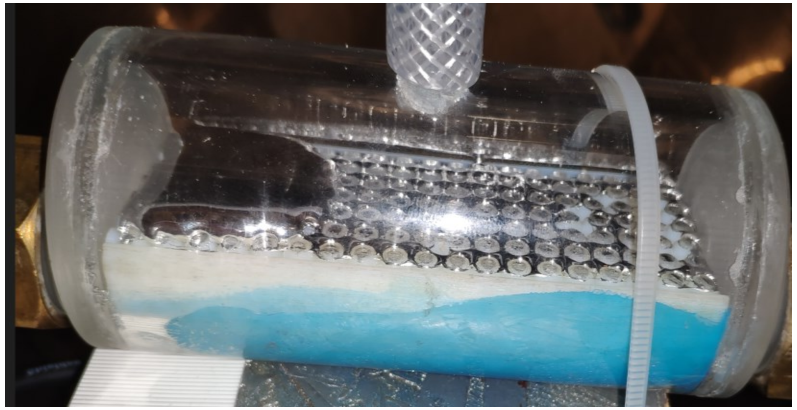


Free surface changes in magnetic field

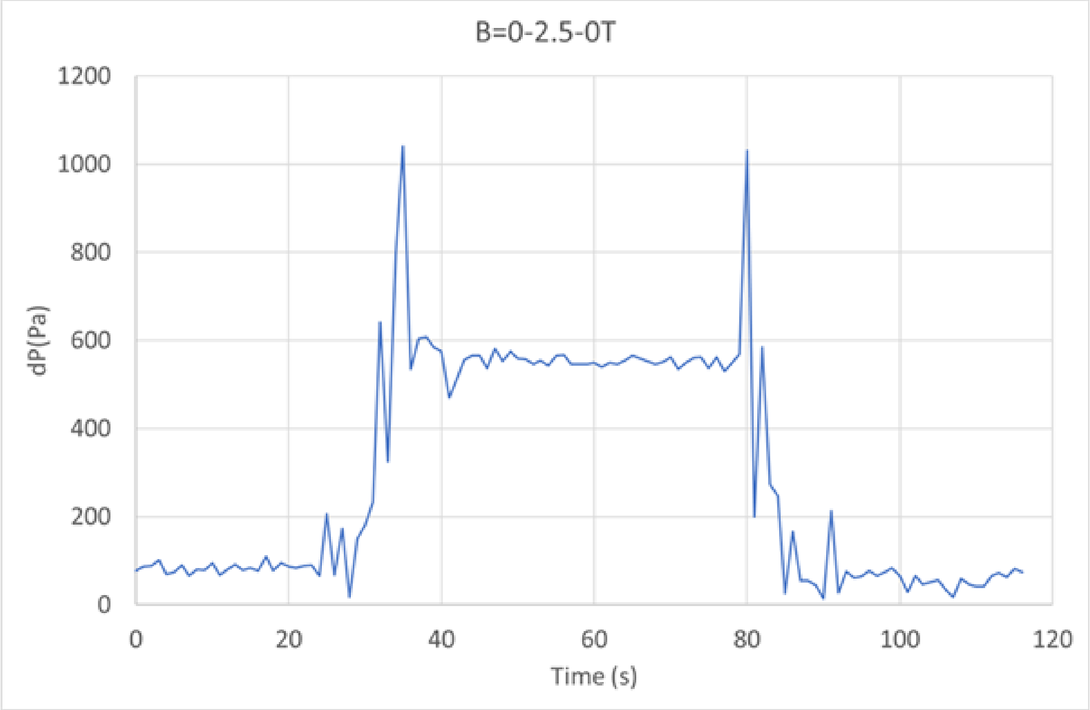
Small flowrate/magnetic field



High flowrate/magnetic field

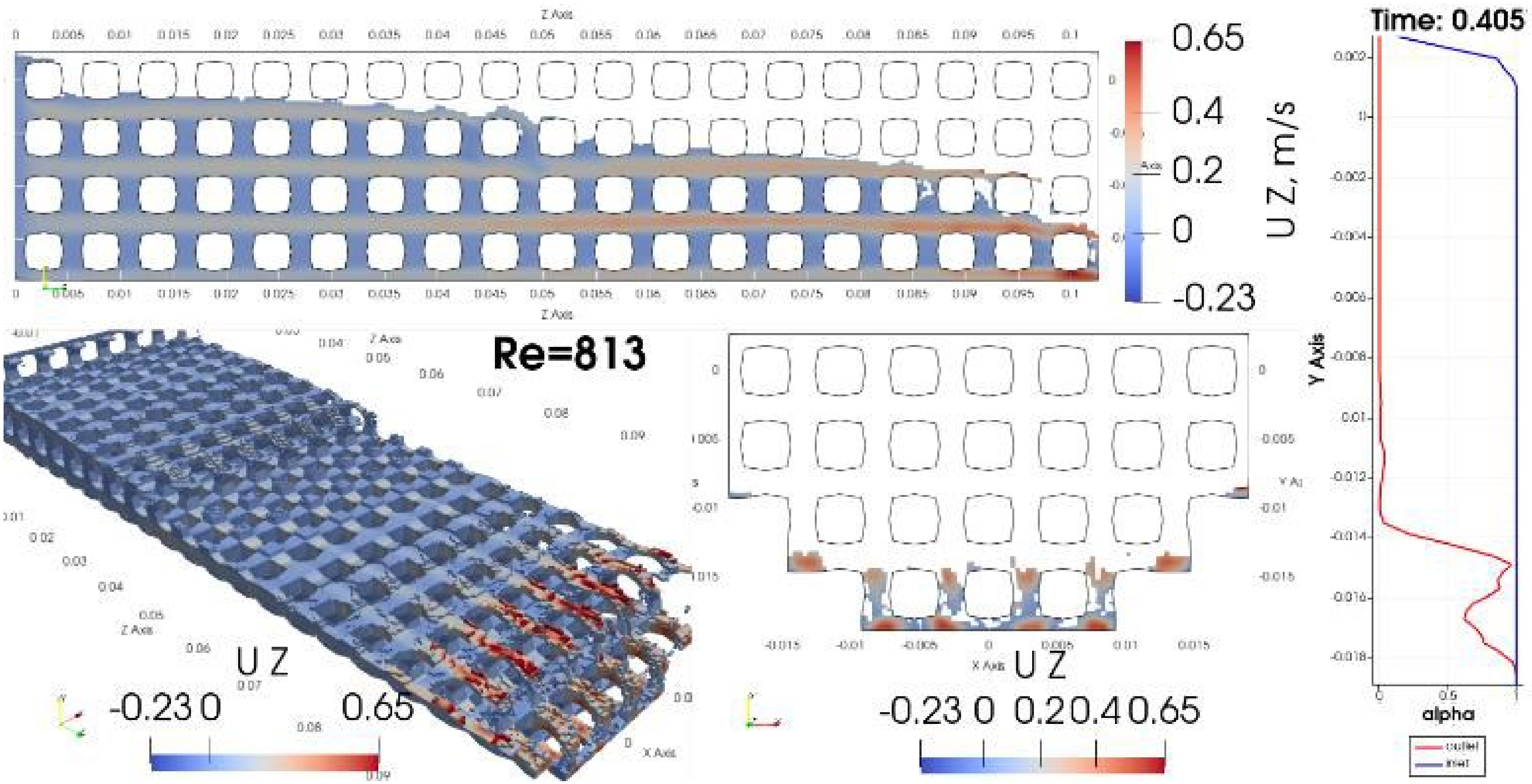


Sloped free surface elevated at inlet and lowered at outlet

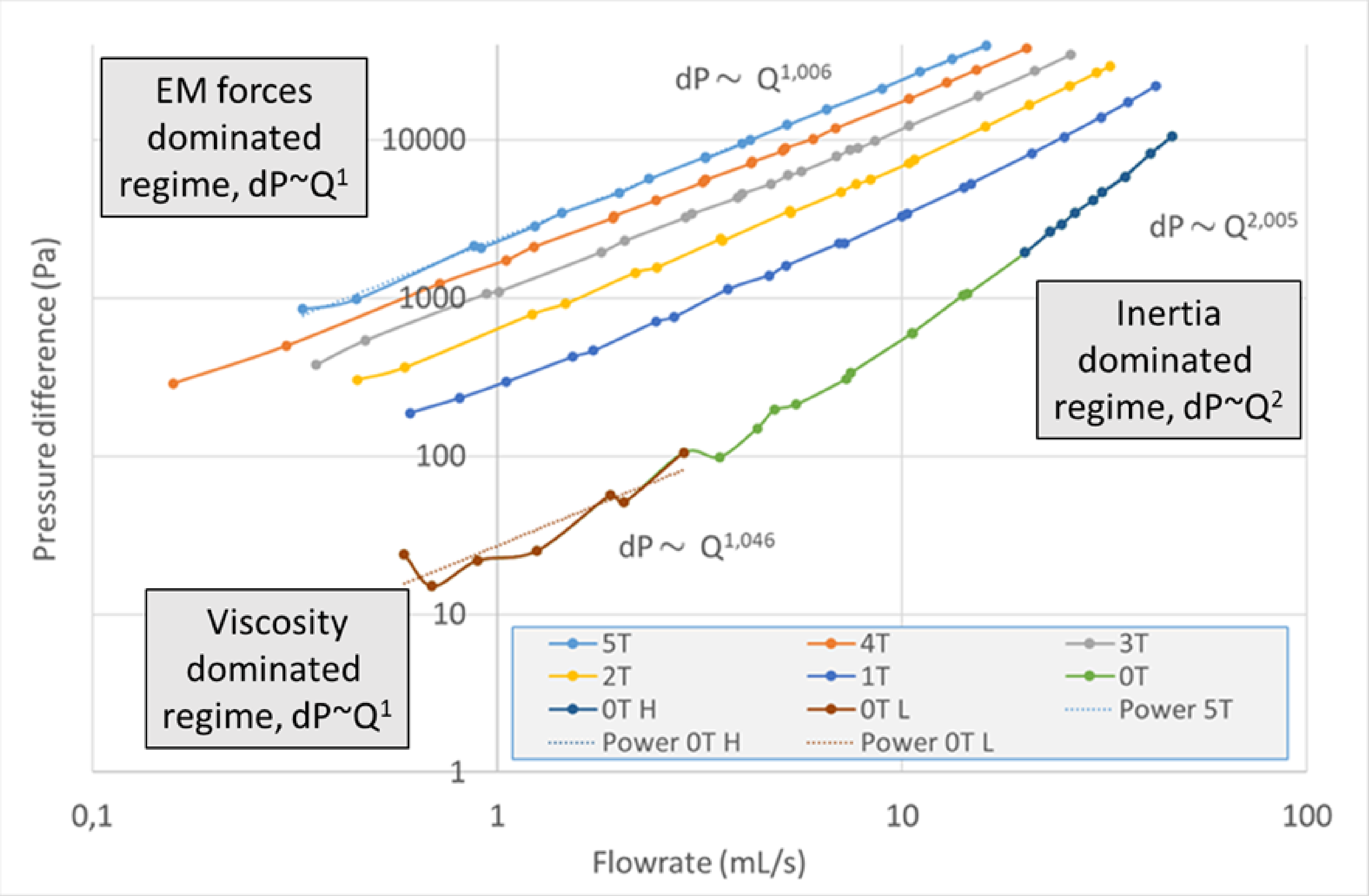


Pressure drop moving test section in/out magnetic field

COMSOL VOF results for simplified geometry without magnetic field

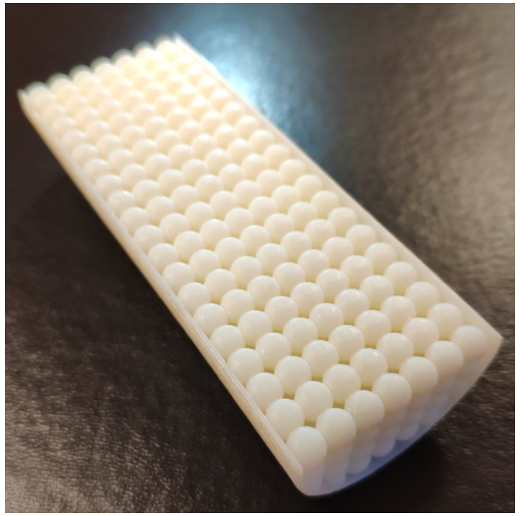


Results and interpretation (P-Q curves in various regimes)

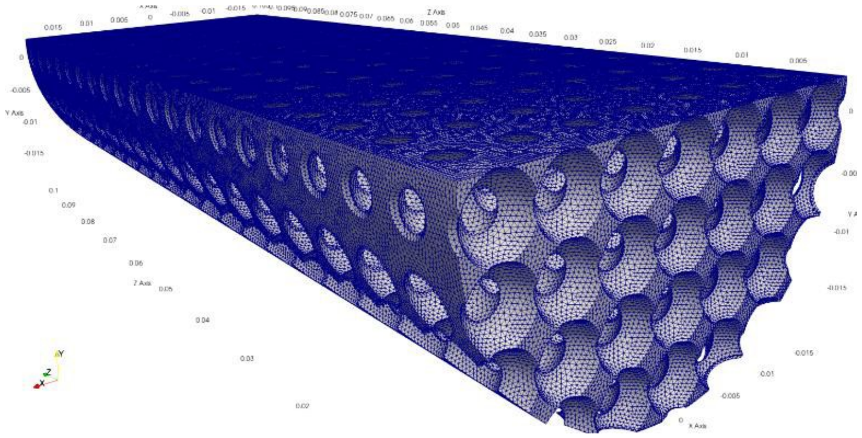


Models of two-phase flow in pore space

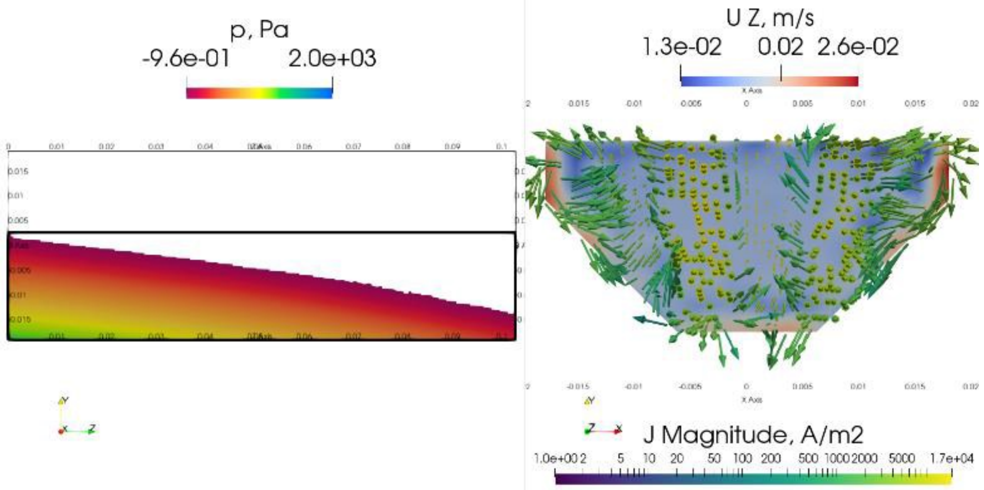
Real geometry

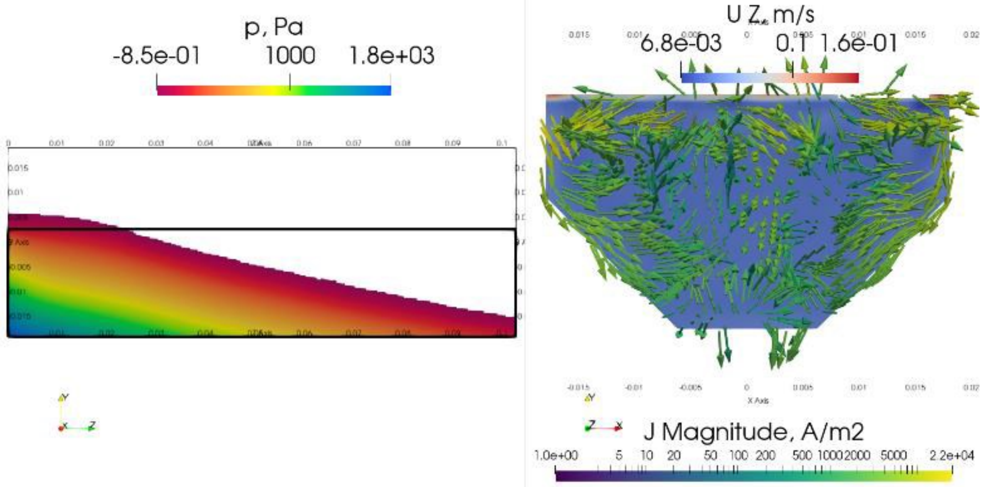


Real geometry 3D model

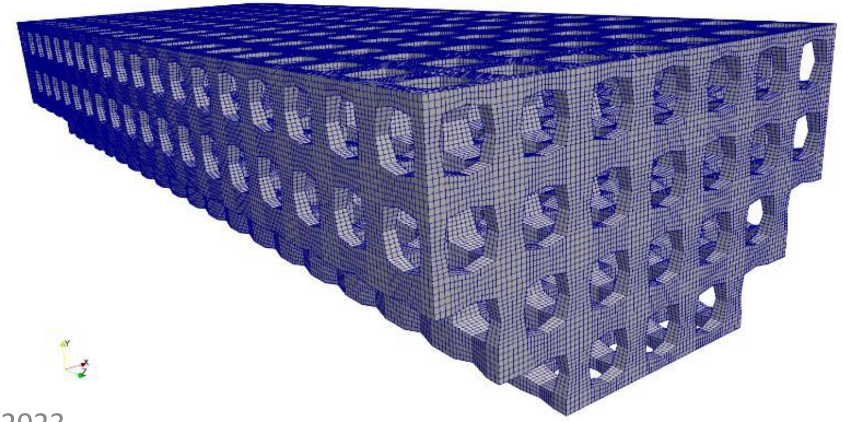


B_x=2T, Q=10ml/s and 25 ml/s



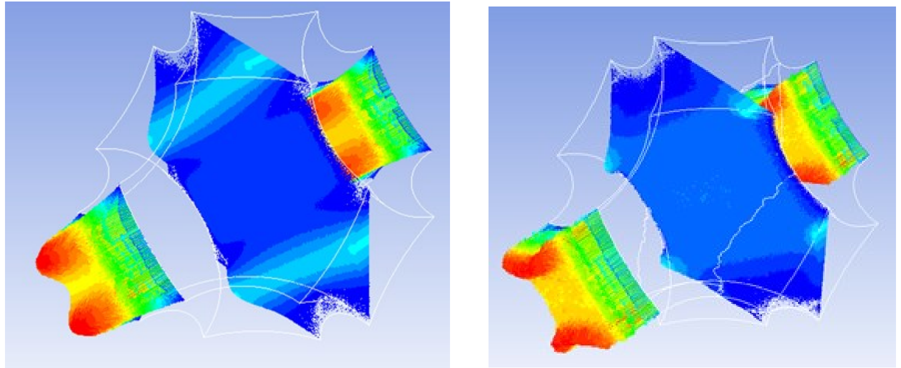


Simplified geometry



Conducting walls case (induced/imposed current can go through the solid phase)

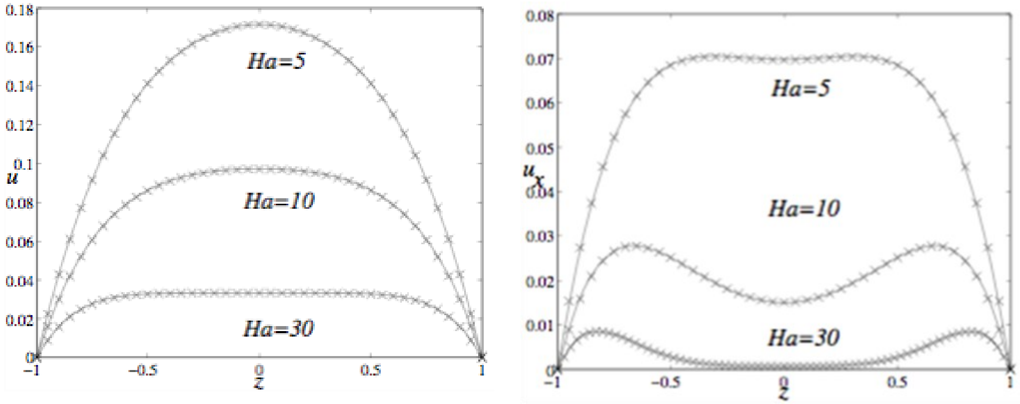
B_{xy}, *Ha*=50



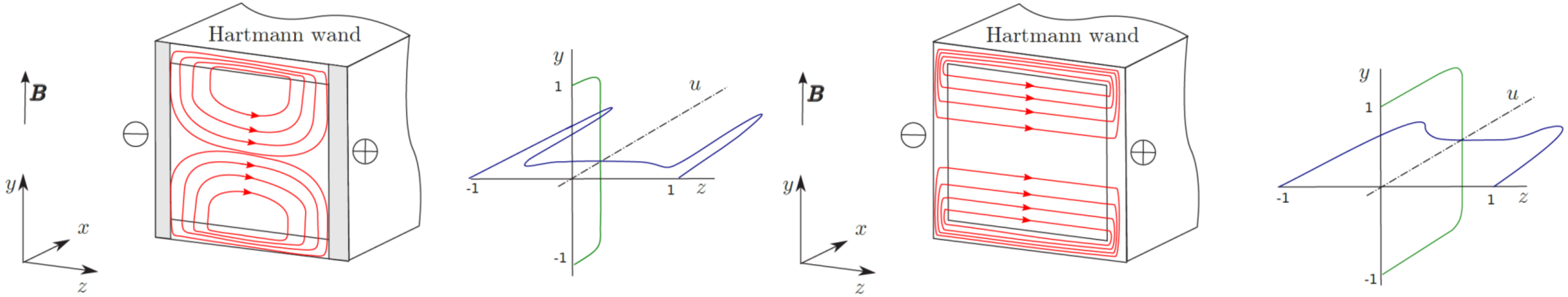
Isolated walls

Ideally conductive walls

Hartman flow with conductive and non-conductive walls



Hunt flow at different wall conductions



$$\mathrm{Ha} = BL\sqrt{\frac{\sigma}{\mu}}$$

Müller, U. and Bühler, L. (2001). Magnetofluiddynamics in Channels and Containers. Springer, Wien, New York. ISBN 3-540-41253-0.

Further work (2023 and beyond)

- Experimental study of TEMC processes in simplified/scaled systems
- Numerical modeling of TEMC processes in test/realistic geometries

- Modify MHD flow in CPS experimental setup for reliable placements of current supplying electrodes and pressure measurements
- Further development of two-phase free surface simulation models for:
  - Quantitative interpretation of hydraulic experiments results
  - Qualitative interpretation of CPS heat transfer testing experiments
- Study of the MHD flow at different wall/matrix conductivities
- 3D printed CPS systems

Thank You for attention !

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