Numerical prediction of the pressure drop in the LiMeS CPS

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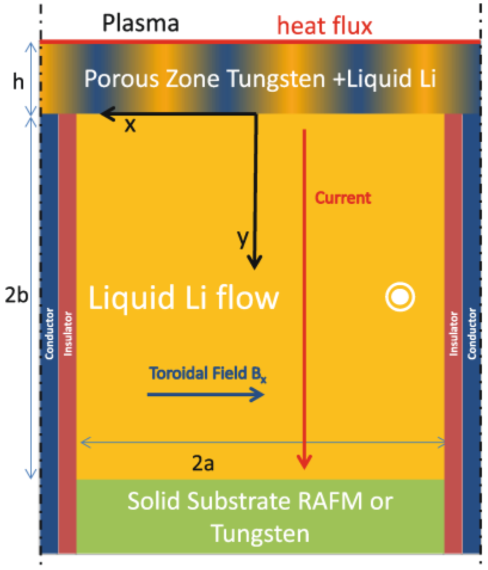
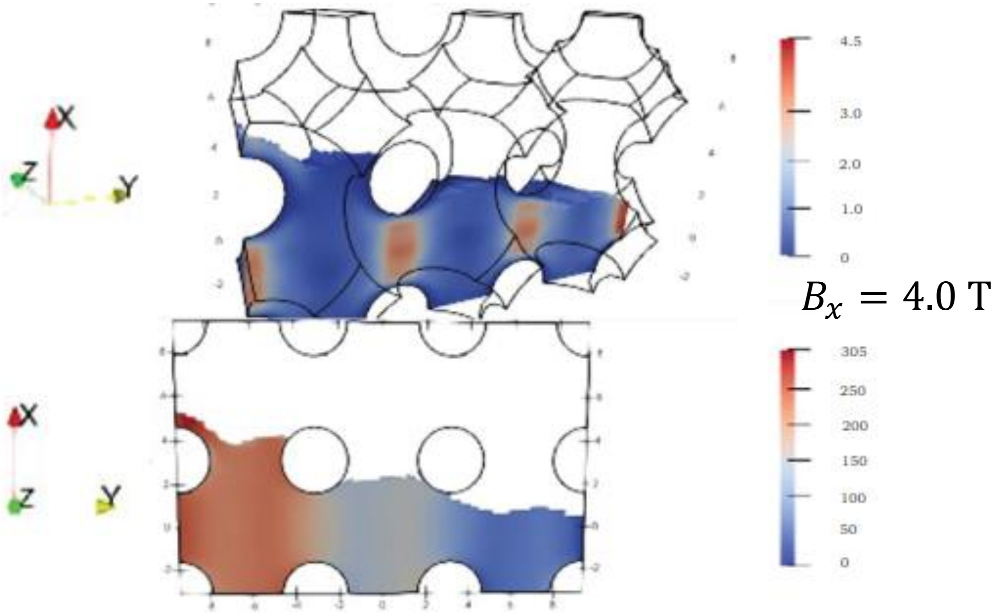
Main Objective: Numerical prediction of the pressure drop in a CPS in LiMeS-PSI

Numerical Modelling in literature:

1. Flow simulation of few complex porous structure cells (no heat transfer, two phase);
2. Porous media modeled as a solid with average properties, more focused on heat transfer;

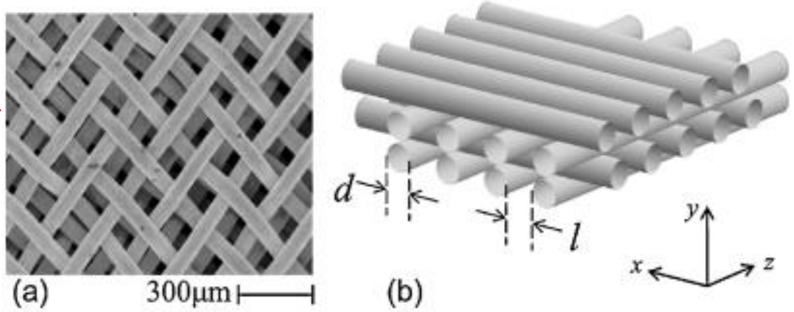


[2] A. Khodak et al., *Nuclear Materials and Energy* (2021)



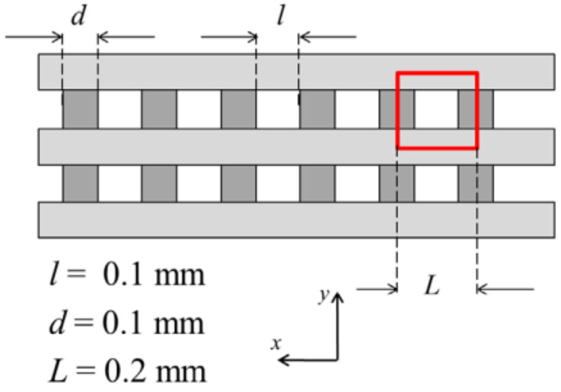
[1] D. Berenis et al., *Magnetohydrodynamics* (2023)

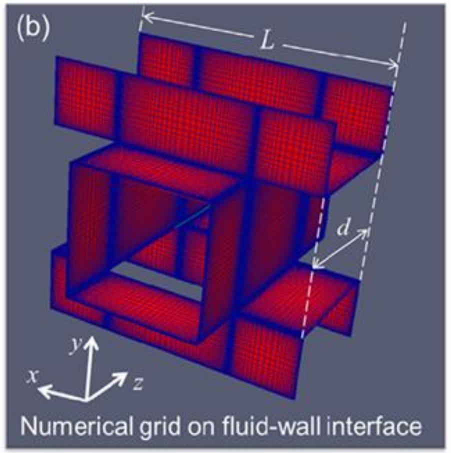
3. Flow simulation in a simplified porous structure cell (no heat transfer, single-phase);

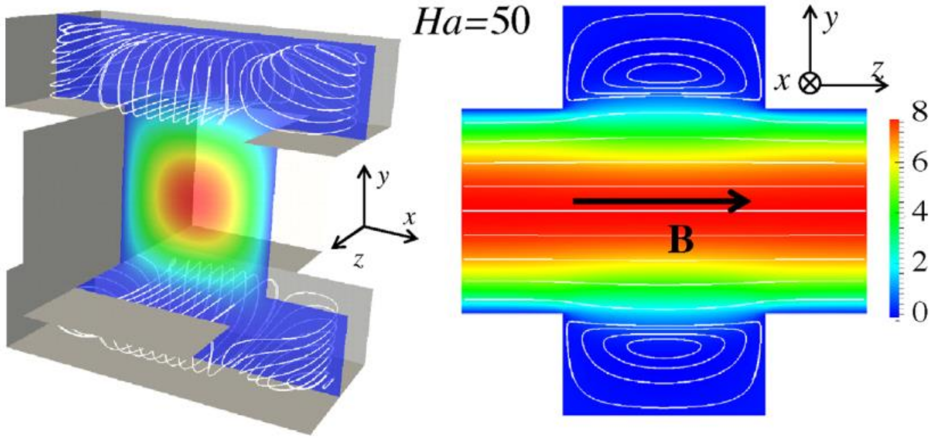


100 μm CPS

CPS model geometry







[3] L. Bühler et al., *Fusion Engineering and Design* (2015)

Proposed modelling strategy:

- Solve two-phase (VoF) MHD NS equations adding as a source term the Darcy-Forchheimer contribution in the momentum equation with OpenFOAM. It will be added only in the porous media region.

$$\nabla\cdot\mathbf{u} = 0$$

$$\partial\alpha/\partial t + \nabla\cdot(\alpha\,\mathbf{u}) = 0$$

Darcy-Forchheimer contribution

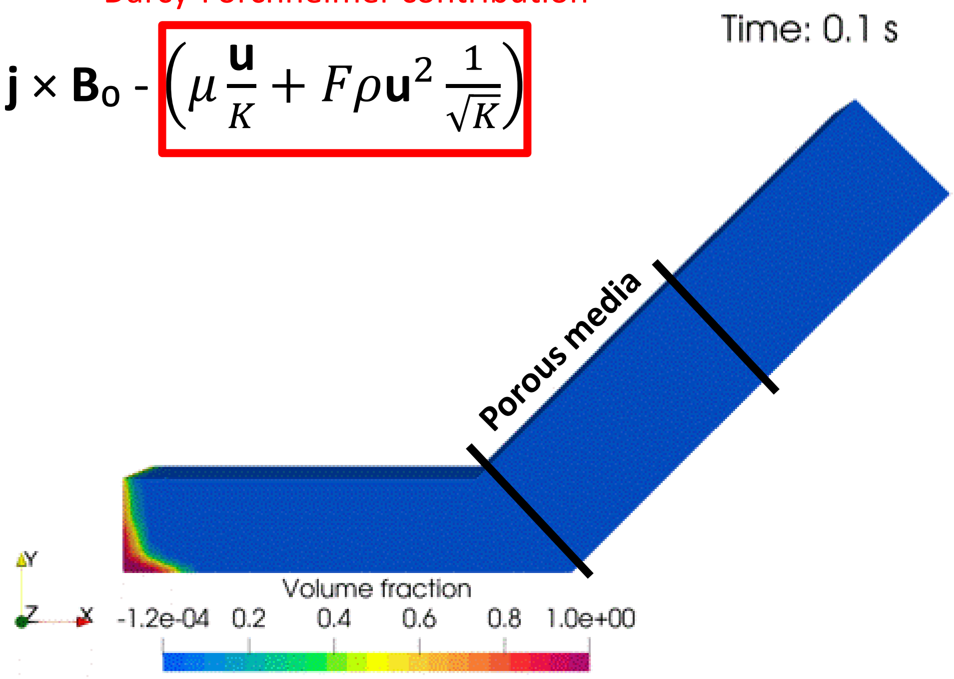
$$\rho\,[\,\partial\mathbf{u}/\partial t + (\mathbf{u}\cdot\nabla)\mathbf{u}\,] = -\nabla p + \mu\,\nabla^2\mathbf{u} + \gamma\,\kappa\,\nabla\alpha + \rho\,\mathbf{g} + \mathbf{j}\times\mathbf{B}_0 - \boxed{\left(\mu\frac{\mathbf{u}}{K} + F\rho\mathbf{u}^2\frac{1}{\sqrt{K}}\right)}$$

$$\nabla^2\phi = \nabla\cdot(\mathbf{u}\times\mathbf{B}_0)$$

$$\mathbf{j} = \sigma\,(\,-\nabla\phi + \mathbf{u}\times\mathbf{B}_0\,)$$

Example:

- Hydrodynamic flow of water in an angle duct with a porous media (OpenFOAM tutorial)



Advantages:

- Adaptable to capillary structures of different geometries
- Joint simulation of duct LM flow + CPS

Requirement:

- A priori knowledge about of permeability K and Forchheimer coefficient F

Limit:

- No local effects modeled in the porous media

Validation:

- Pressure drop comparison with experimental and numerical results:
  I. L. Buligins et al., *MHD Flow in Simple Cubic Periodic Array Geometry*, Journal of Fusion Energy, 2023, https://doi.org/10.1007/s10894-023-00390-8
  II. C. You et al., *Liquid metal flow characteristics in self-supplying capillary porous channels under strong magnetic field for fusion devices,* Physics of Fluids, 2025, https://doi.org/10.1063/5.0256993
  III. J.D McWhirter et al., *Magnetohydrodynamic Flows in Porous Media II: Experimental Results,* Fusion Technology, 1998, http://dx.doi.org/10.13182/FST98-A63
  IV. Other unpublished results available from project partners.

Activities

First year 2026
M0-M6: Code testing and input deck preparation
M7-M11: Validation activities with experimental data: 1. Buligins 2023, 2. You 2025, 3. McWhirther 1998
M11-M12: Report writing

Second year 2027
M13-M16: Calibrating (or extending) the Darcy-Forchheimer model and repeat validation matrix.
M16-M22: Pressure drop prediction for LiMeS-PSI CPS
M23-M24: Report writing

Thank you for your attention