

# Liquid metal MHD flow influence on heat transfer coefficient in fusion reactor blankets



Suárez, D.\* , Iraola, E., Lampón, C., Mas de les Valls, E., Batet, L.  
 Universitat Politècnica de Catalunya (UPC), ANT Research Group, Barcelona, Spain  
 \* daniel.suarez.cambra@upc.edu



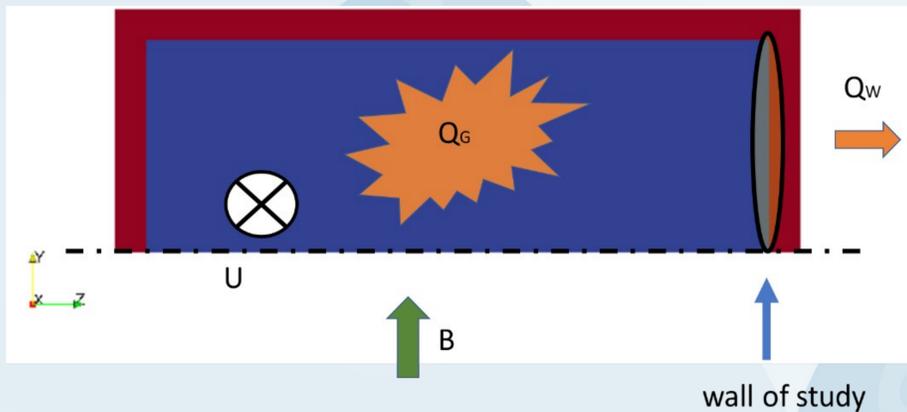
## Motivation

Liquid Metal flow in the DCLL blanket channels is a complex phenomena involving multi-material magnetohydrodynamics and buoyancy forces.

Most of the heat deposited in the channels is transferred to the balance of plant while some of it will be absorbed by the channel walls helium cooling system.

The work carried out at UPC analyzes the variation of the main heat transport parameters with respect to the dimensionless numbers that balance the flow forces, ie, Hartmann number (Ha), Reynolds number (Re), Grashof number (Gr), Grashof ratio (GrR) and wall conductivity ratio (C<sub>w</sub>).

The case set up:



$$Ha = BL \sqrt{\frac{\sigma}{\rho\nu}} \quad Re = \frac{\rho \cdot \bar{U} \cdot D_h}{\mu} \quad C_w = \frac{\sigma_w \cdot \tau_w}{\sigma \cdot L_h} \quad Gr = \frac{g\beta\Delta TL^3}{\nu^2} \quad GrR = \frac{Q_w}{Q_G}$$

The red region represents SiC ceramic channel walls while blue region corresponds to liquid metal. The domain is a 2D cross-section of a DCLL channel. The flow is assumed to be fully developed and the domain has been halved thanks to the symmetry condition.

## Buoyant MHD model

All calculations in this work have been done with the following set of equations with liquid-solid coupling for a buoyant fully developed flow:

$$\begin{aligned} \nabla \cdot U &= 0 & \theta &= T - T_m \\ \frac{\partial U}{\partial t} + (U \cdot \nabla)U &= -\frac{\nabla p}{\rho} + \nu \nabla^2 U + \frac{j \times B}{\rho} - \beta \theta g & \frac{\partial \theta}{\partial t} + (U \cdot \nabla)\theta &= \frac{k}{\rho C_p} \nabla^2 \theta + S_{th} \\ \nabla^2 \varphi &= \nabla \cdot (U \times B) & S_{th} &= \frac{1}{\rho C_p} q_0 e^{-mz} \\ j &= \sigma_m (-\nabla \varphi + U \times B) \end{aligned}$$

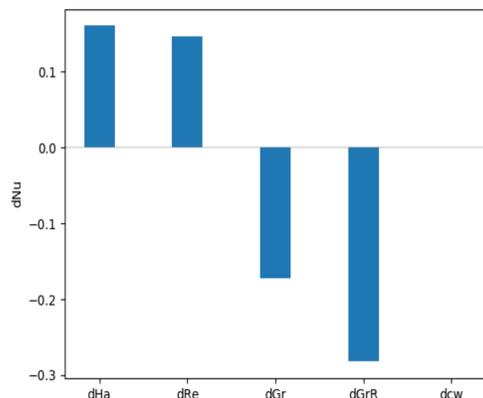
## Conclusions

The following figure shows the influence of each variable into the Nusselt number.

Other conclusions of the study indicate that either an increase in Re, Ha and Gr, the maximum temperature increases in bulk and in the wall, as well as its gradient.

## Perspectives

The range of applicability of the fully-developed model is still uncertain. A 3D stability map depending on the dimensionless numbers is under investigation.



## Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No. 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

The authors thank as well the contribution of Associació/Col·legi d'Enginyers Industrials de Catalunya with Fundació Caixa d'Enginyers' financial support.

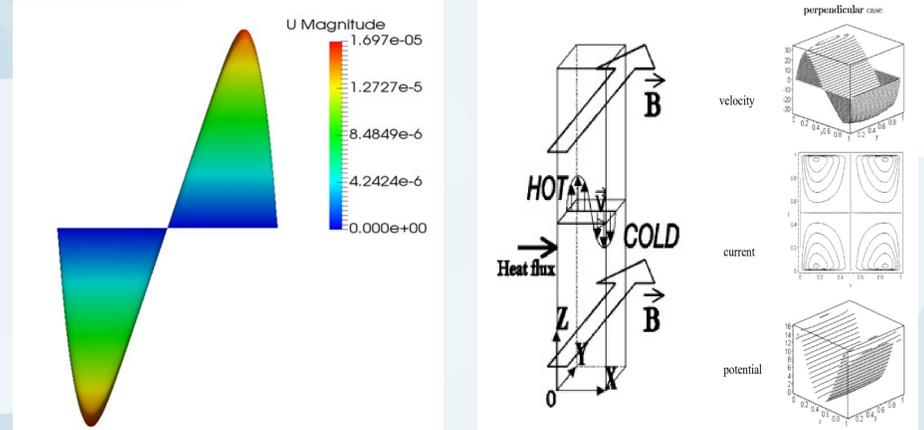
## References

- [1] Barleon, L., Casal, V., & Lenhart, L. (1991). MHD flow in liquid-metal-cooled blankets. *Fusion Engineering and Design*, 14(3-4), 401-412. [https://doi.org/10.1016/0920-3796\(91\)90021-H](https://doi.org/10.1016/0920-3796(91)90021-H)
- [2] Causey, R. A., Karnesky, R. A., & Marchi, C. S. (2009). Tritium Barriers and Tritium Diffusion in Fusion Reactors.
- [3] Garcinuño, B., Rapisarda, D., Antunes, R., & Utili, M. (2018). The tritium extraction and removal system for the DCLL-DEMO fusion reactor. <https://doi.org/10.1088/1741-4326/aac889>
- [4] Mas de les Valls, E. (2011). Development of a simulation tool for MHD flows under nuclear fusion conditions. PhD thesis.
- [5] Mas de les Valls, E. (2017). Magneto-convection in PbLi vertical ducts Project. WPBB-DEL-BB-5.2.2-T002-D002.
- [6] Mas De les Valls, E., Sedano, L. A., Batet, L., Ricapito, I., & Aiello, A. (2008). Lead - lithium eutectic material database for nuclear fusion technology, 376, 353-357. <https://doi.org/10.1016/j.jnucmat.2008.02.016>
- [7] Mistrangelo, C. (2014). Identification of requirements for accurate numerical MHD predictions and task work plan. WPBB-DEL-D-521-01.
- [8] Ni, M., Munipalli, R., Morley, N. B., Huang, P., & Abdou, M. A. (2007). A current density conservative scheme for incompressible MHD flows at a low magnetic Reynolds number. Part I: On a rectangular collocated grid system, 227, 174-204. <https://doi.org/10.1016/j.jcp.2007.07.025>
- [9] Tagawa, T., Authié, G., & Moreau, R. (2002). Buoyant flow in long vertical enclosures in the presence of a strong horizontal magnetic field. Part 1. Fully-established flow, 21, 383-398.
- [10] Urgorri, F. R., Moreno, C., Carella, E., Rapisarda, D., Fernandez-Bergeruelo, I., Palermo, I., & Ibarra, A. (2017). Tritium transport modeling at system level for the EUROfusion Dual Coolant Lithium-Lead breeding blanket.
- [11] Urgorri, F. R., Smolentsev, S., Fernandez-Bergeruelo, I., & Rapisarda, D. (2018). Magnetohydrodynamic and thermal analysis of PbLi flows in poloidal channels with flow channel insert for the EU-DCLL blanket.

## Methodology

### 1. Validation

The first part of the work has been oriented to speed up the code. The buoyant MHD flow in an infinite enclosure (by Tagawa [9]) has been selected as the validation case for the code improvement.



The code improvement has shown the same accuracy as the previous code in the validation case. The new code is two orders of magnitude faster before parallelization (a new feature for this code).

### 2. Parameters of interest and variables definition

A total of seven parameters of interest have been analyzed in this work: (1) the Nusselt number, (2) maximum vorticity, (3) maximum velocity, (4) maximum theta (θ) in the fluid and (5) in the wall, (6) maximum θ gradient in the wall, (7) dimensionless pressure drop coefficient (kp).

The Nusselt number is defined as:  $Nu = \frac{h \cdot L_s}{k} \quad h = \frac{Q_{bw}}{A_{bw} \cdot (T_b - T_{bw})}$

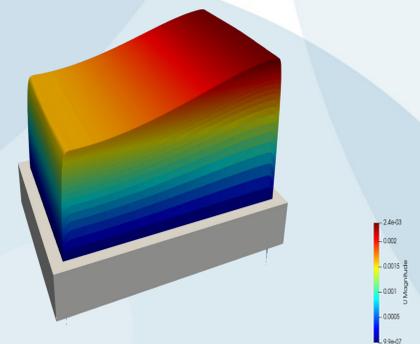
The study consists of 32 simulations using all combinations of dimensionless numbers (variables) that guarantee fully developed condition. They are shown in the following table:

Ha	Re	Gr	GrR	C <sub>w</sub>
3000	3600	10e6	0.02	1e-12
2400	3000	5e6	0.01	1e-16

$$\frac{\partial Parameter}{\partial Variable} \approx \frac{\frac{Param_2 - Param_1}{Param_2}}{\frac{Var_2 - Var_1}{Var_2}}$$

### 3. Results

A fully developed flow profile has been obtained for all the simulations as the one shown on the right.



The temperature distribution in one of the cases can be seen in the following figure, as well as the maximum temperature dependence on the dimensionless numbers:

