EUROMECH COLLOQUIUM 651
International Colloquium on Films, bubbles, droplets and phase change

August 25th-29th 2025, Metz, France
https://euromech.org/colloquia/colloquia-2025/651

Advancing Liquid Metal Divertors in magnetic confinement devices: Plasma Interaction, Heat Exhaust, and Fabrication Challenges

J. Moritz[1], R. Avril, M. Spinosi, P. Lohmuller, F. Brochard, T. D. Le

Keywords: Magnetic confinement Fusion, heat exhaust, liquid metal, capillary structures

Due to imperfect magnetic confinement in fusion devices, energetic losses are directed toward the internal walls, primarily the divertor, where heat flux can reach 10-20 MW/m^2. To withstand these extreme conditions, plasma-facing components (PFCs) in ITER rely on actively cooled tungsten monoblocks [1]. However, tungsten faces significant longevity challenges due to neutron embrittlement, dust generation, local melting, and cracking [2], driving the search for alternative PFCs to ensure high availability in future fusion power plants.

Liquid metal (LM)-based PFCs offer a promising solution by mitigating these limitations through continuous liquid replenishment. Two main concepts have emerged since the 1970s. The first consists of flowing LM directly along plasma-facing walls, particularly in the divertor. Theoretically, LM streams can be actively driven along the inner vacuum chamber walls in tokamaks [3]. This approach is particularly attractive when using low-Z materials like lithium, which also has favorable coolant properties.

Another approach relies on Capillary Porous Systems (CPS), where a porous structure is infiltrated with low-melting-point metals such as Li or Sn [4]. CPS technology uses capillary forces to retain LM, preventing splashing due to magnetohydrodynamic (MHD) effects. Capillarity also enables LM replenishment after evaporation, ensuring self-healing properties and continuous operation under high heat fluxes. Despite its resilience, CPS faces challenges such as limited pore geometry control, incomplete understanding of capillary flow dynamics, bubble formation, and manufacturing constraints.

This presentation compares both approaches regarding plasma contamination by LM droplets and metal vapor, heat exhaust efficiency and technological feasibility. For flowing LM, a key issue is Li migration toward the plasma core, which can impact plasma performance and radiation losses. We will discuss the mechanisms driving Li transport and its implications for fusion plasmas. For CPS, the main challenges involve fabrication and infiltration, as precise pore geometry control is crucial for LM retention and replenishment, yet current techniques limit porosity and structural integrity. Numerical simulations of heat transfer through the CPS with consideration of ML evaporation/redeposition are performed to give insight into the pore structure effects on thermal performance. We will present recent advances and key developments needed for their integration into future fusion reactors.

References:

[1] R. Pitts et al, Nucl. Mater. Energy **20**, 100696 (2019).
[2] Y Corre, the WEST team et al. Phys. Scr. **96**, 124057 (2021).
[3] L.E. Zakharov, Phys. Rev. Lett. **90**, 045001 (2003).
[4] P. Rindt et al, Nucl. Fusion **61**, 066026 (2021).

1 University of Lorraine (e-mail: jerome.moritz@univ-lorraine.fr).