Simulations of droplet ejection from metallic plasma-facing components

L. Vignitchouk[1], A. Khodak[2], S. Ratynskaia[1], I. Kaganovich[2]

[1] *KTH Royal Institute of Technology, Space and Plasma Physics, Stockholm, Sweden*

[2] *Princeton Plasma Physics Laboratory, Princeton, United States of America*

Damage due to transient surface melting has been identified as a key factor in the determination of metallic plasma-facing component (PFC) lifetime in magnetic confinement fusion reactors. Transient melting events are typically caused by off-normal or pulsed energy loads, such as those associated with large edge-localized modes (ELM), unipolar arcs and disruptions. Once a melt pool is created, it is susceptible to flow before re-solidifying, which may lead to significant changes in the PFC surface morphology, and hence a degradation of its power-handling capabilities [1]. In some cases, part of the melt layer can be accelerated enough to detach as droplets, which may then solidify into dust particles. This mechanism has in fact been highlighted as one of the main dust sources in AUG [2], JET [3] and ITER [4].

Depending on the nature of the heat and momentum sources, re-solidification times range from a few tens of nanoseconds to tens of milliseconds, while the typical droplet size is 1-100 μm. Due to such short length and time scales, direct experimental observation in tokamaks and linear plasma generators is highly challenging. Therefore, the large majority of the available experimental data relates to the state of the damaged PFC after a melt event [2,3,5-8], and numerical simulations offer a critical contribution in furthering the understanding of droplet ejection.

Although fully self-consistent simulations accounting for all the relevant multi-phase flow dynamics and plasma-surface interactions are considered out of reach, highly detailed models have been developed in the context of cathode spots in vacuum arcs [9,10], which are recognized as very similar to unipolar arcs on PFCs. For ELM and disruption scenarios, the existing numerical tools rely on simplifying assumptions, such as the shallow water approximation in MEMOS [11] or the hypothesis of negligible heat diffusion in [12].

In this work, free-surface flow simulations are carried out with imposed heat and momentum sources intended to mimic unipolar arc conditions. A customized version of the general-purpose ANSYS code suite is used, which properly accounts for the coupling between nonlinear fluid flow, heat transfer and phase transitions. Benchmarks against published cathode spot simulations are presented [9], followed by comparisons with recent experimental measurements of copper droplet size and velocity distributions in a vacuum arc [13].

[1] R. A. Pitts *et al*, *Nucl. Mater. Energy* **12** (2017) 60
[2] V. Rohde and M. Balden, *Nucl. Mater. Energy* **9** (2016) 36
[3] I. Jepu *et al*, *Nucl. Fusion* **59** (2019) 086009
[4] M. Lehnen *et al*, *J. Nucl. Mater.* **463** (2015) 39
[5] J. W. Coenen *et al*, *Nucl. Fusion* **55** (2015) 023010
[6] K. Krieger *et al*, *Nucl. Fusion* **58** (2018) 026024
[7] S. Bardin *et al*, *J. Nucl. Mater.* **463** (2015) 193
[8] N. S. Klimov *et al*, *Nucl. Mater. Energy* **12** (2017) 433
[9] G. Mesyats and I. Uimanov, *IEEE T. Plasma Sci.* **43** (2015) 2241
[10] H. T. C. Kaufmann *et al*, *Plasma Phys. Control. Fusion* **61** (2019) 095001
[11] E. Thorén *et al*, *Nucl. Mater. Energy* **17** (2018) 194
[12] G. Miloshevsky and A. Hassanein, *Nucl. Fusion* **54** (2014) 043016
[13] P. Siemroth *et al*, *IEEE T. Plasma Sci.* **47** (2019) 3470