Self-consistent simulation of Magnum-PSI target in SOLPS-ITER with a Finite Element Wall model

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Introduction

Solving the power exhaust problem in tokamaks is one of the milestones along the path towards fusion electricity production [1]. In this context, accurate simulation of plasma-surface interaction is of great importance for the determination of heat and particle fluxes towards the divertor of a tokamak. For example, it is expected that during slow transients ITER divertor will have to stand between 10 and $20\,\mathrm{MWm}^{-2}$ [2] and orders of magnitude higher during fast transients. These fluxes are in the thermal limit of known materials, thus the design of cooling systems and divertors to sustain this load is determinant for future reactors.

To support these design activities, the availability of a model which can self-consistently simulate the impinging plasma and the target temperature, accounting for the divertor cooling, would be beneficial. Moreover, it should be mentioned that in the case of a liquid metal divertor [3] a self-consistent coupling is essential, since the plasma and target mutually interact via target evaporation and the consequent plasma cooling [4]. This work presents the coupling between SOLPS-ITER, a widely used code in the fusion community, and a Finite Element Wall model to self-consistently simulate the target behavior in terms of, e.g, surface temperature and/or liquid metal evaporation rate.

In this paper, the first results from the coupling mentioned above to the simulation of Magnum-PSI, a plasma linear device that can reproduce ITER relevant divertor fluxes, are discussed. These simulations will allow to validate the plasma solution provided by SOLPS-ITER with the surface temperature obtained by the target model, increasing the reliability of the code and improving our capability to simulate Magnum-PSI.

SOLPS-ITER for Magnum-PSI simulations

SOLPS-ITER [5, 6] is widely used in the fusion community. However, validation and comparison with experiments is often complicated by the limitations to experimental access in tokamaks. Magnum-PSI [7] is a plasma linear device that can reproduce heat and particle fluxes of those expected at the ITER divertor. Thus, there is an interest in using SOLPS-ITER to simulate Magnum-PSI, as this will allow for validation of the code and to extract information that can

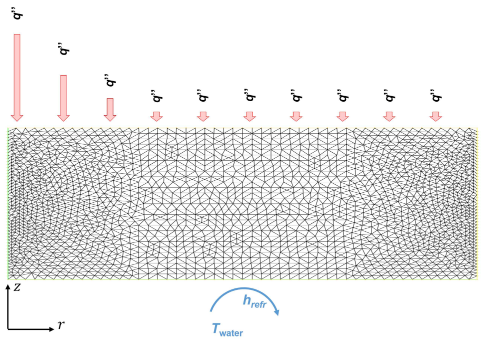

Figure 1: 2D mesh of the tungsten target employed in the simulations. The bottom wall is set to a constant temperature of 180 °C (453 K) to represent an active cooling.

be easily translated to a tokamak divertor, like the relevant atomic and molecular processes near the target.

Nevertheless, the application of SOLPS-ITER to a linear device like Magnum-PSI is not straightforward and requires several aspect to be careful considered. Apart from the obvious change in geometry respect to a tokamak, for Magnum-PSI the parallel direction represents the axial coordinate z, a new set of boundary conditions to represent the plasma source need to be incorporated. Experimental data from Thomson Scattering (TS) measurements are used as input profiles for plasma density and temperature. The electric potential at the source, which in Magnum-PSI controls the amount of Ohmic heating in the plasma beam, is adjusted so that temperatures in the target chamber remain close to experimental data [8].

Finite Element Target Model

Currently, SOLPS-ITER is being coupled with a FreeFem++ [9] finite element model to self-consistently compute the target properties, accounting for the target material, its shape and the cooling system. This provides a flexible, fast running 2D transient heat conduction solver. The model receives the heat fluxes towards the target computed by SOLPS-ITER and returns the target temperature. The surface temperature can be then extracted and passed back to SOLPS-ITER. This cycle is repeated until plasma, neutrals and target temperature reach a converged state.

For the case presented here, a solid tungsten target is employed, and the active cooling is imposed by setting a constant temperature at the bottom surface of 180 °C (453 K). The target temperature is recalculated at each time step taking into account the plasma heat flux towards the target and this value is passed back to SOLPS-ITER. The 2D model employed to represent a Magnum-PSI target can be found in Fig. 1.

Future simulations of the target will include self-consistent calculated recycling parameter or

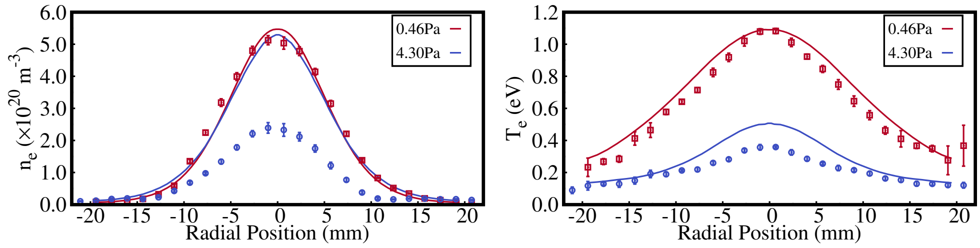

Figure 2: Electron density (left) and temperature (right) at the Thomson Scatering (TS) target position for two neutral pressures at the target chamber. SOLPS-ITER results (solid line) agree with experimental TS data (data points), although discrepancies in the temperature for the 4.30 Pa case appear.

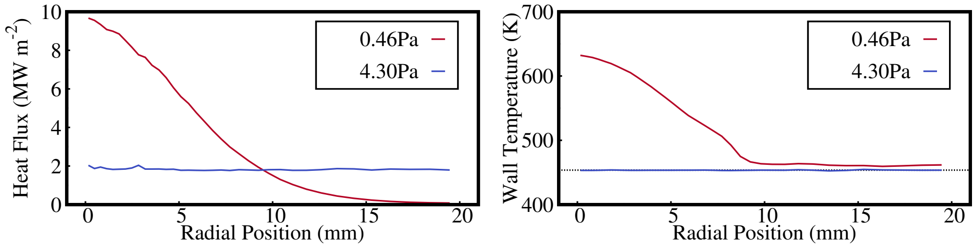

Figure 3: Target heat flux (left) and surface temperature (right) provided by the finite element wall model. For the high pressure case, surface temperature is reduced to the cooling temperature as plasma heat flux has been mitigated upstream by interaction with neutral particles.

the evaporation flux when a porous material filled with a liquid metal is used as a target.

Coupled simulations

To test the coupling between SOLPS-ITER and the FreeFem++ target model a *high density* case is used. In this plasma scenario, density close to the target are around $10^{21}\,\mathrm{m}^{-3}$ and temperatures around 1 eV. Two different neutral pressures in the target chamber are analysed, low (0.46 Pa) and high (4.30 Pa), representing attached and detached plasma scenarios, respectively.

Figure 2 presents the comparison of SOLPS-ITER simulations and experimental TS data for the cases described above. SOLPS-ITER captures the temperature reduction observed experimentally when the amount of neutrals near the target is increased by gas puffing. However, discrepancies appear between the simulations and experiments, particularly for the electron density in the high pressure case. Although the cause of this discrepancy is not clear yet, it is expected that the coupling with the target finite element model will provide a much more realistic scenario.

Figure 3 depict the heat flux hitting the target and the surface temperature provided by the FreeFem++ model. For the low pressure case, a Gaussian-like heat flux profile impacts the target, which results in a temperature profile with an increase of more than 100 K near the plasma beam peak. However, when the Magnum-PSI plasma beam is mitigated by gas puffing, target temperature drops to the one set by the bottom cooling system.

Conclusions

The widely use edge plasma code SOLPS-ITER has been successfully applied to the plasma linear device Magnum-PSI. Results are in qualitatively agreement with experimental data although some discrepancies still appear. The code has been successfully coupled with a finite element target model based on the open-source FreeFem++ language. The target temperature has been self-consistently computed based on the heat fluxes in two scenarios: low and high neutral pressure. For a high pressure case, which represents a detached plasma, the temperature of the target drops to the temperature set by the cooling system. Further work is currently ongoing to close the self-consistent loop passing multiple parameters from FreeFem++ to SOLPS-ITER.

Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them. This work was carried out on the Dutch national e-infrastructure with the support of SURF Cooperative and the EUROfusion High Performance Computer Marconi-Fusion hosted at Cineca (Bologna, Italy). This work is part of the research programme "The Leidenfrost divertor: a lithium vapour shield for extreme heat loads to fusion reactor walls" with project number VI.Vidi.198.018, which is (partly) financed by NWO.

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