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

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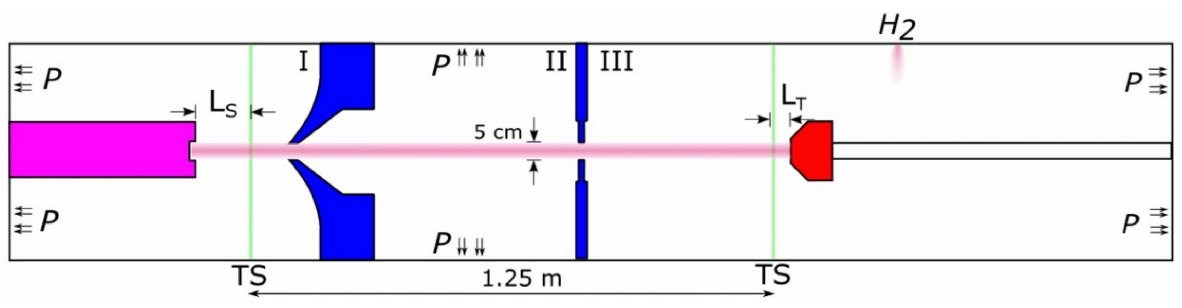
Introduction

- Solving the power exhaust problem in tokamaks is among the milestones along the path towards fusion electricity production.
- A key role in the power exhaust is played by neutral particles coming from refueling, recycling, impurities, outgassing and gas puffing, which interact with the edge plasma.
- The behavior of neutral particles is typically simulated via Monte Carlo codes such as Eirene [1], whereas the edge plasma is simulated via multi-fluid codes often based on the Braginskii equations such as B2.5 [2].
- Simulation of linear plasma devices such as Magnum-PSI with SOLPS-ITER, the combination of B2.5 with Eirene, used widely in the fusion community for edge plasma simulation, can improve the understanding of the complex plasma-surface interactions which will occur at the divertor of e.g. ITER.
- Also, liquid metal targets are easier to test in Magnum-PSI than in tokamaks, which means that this device is an excellent testbed to study new innovative ways to reduce the heat and particle flux towards the target.

Fig. 1: Schematic of Magnum-PSI three chambers: Source (I), Middle (II) and Target (III)



Coupled case

- SOLPS-ITER (B2.5 + Eirene) is being used to simulate Magnum-PSI in a wide variety of plasma conditions.
- Current simulations of experiments focus on detached plasma operation by gas puffing and on liquid metal targets, which are two possible strategies to reduce the heat and particle fluxes to the divertor targets.
- Simulation results for low neutral pressure cases show quite good agreement with the experiments, whereas higher pressure cases still show some mismatch, particularly for the electron density.

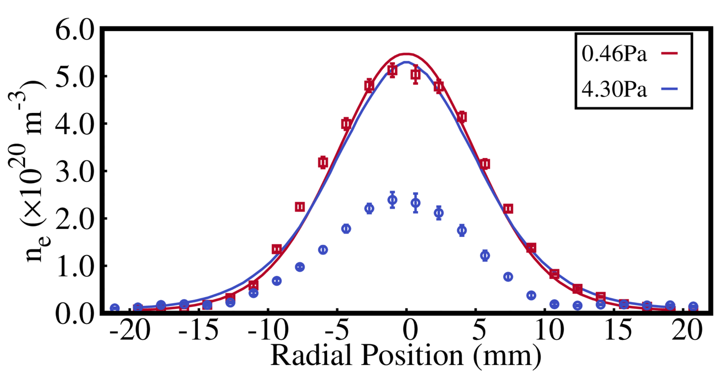


Fig. 2: Electron density at TS target position (z=0m) at two neutral pressures. Solid line is SOLPS-ITER simulation. Data points are TS measurements.

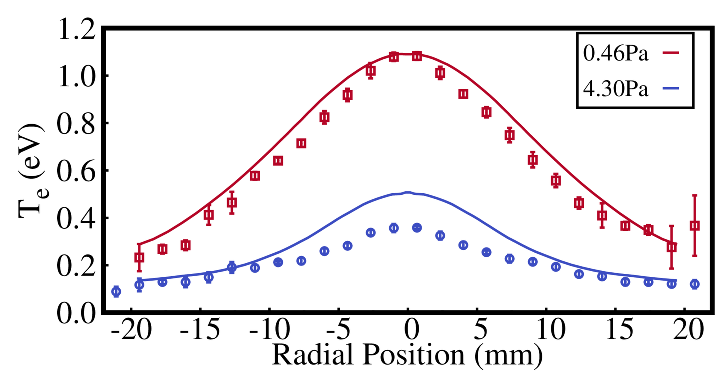


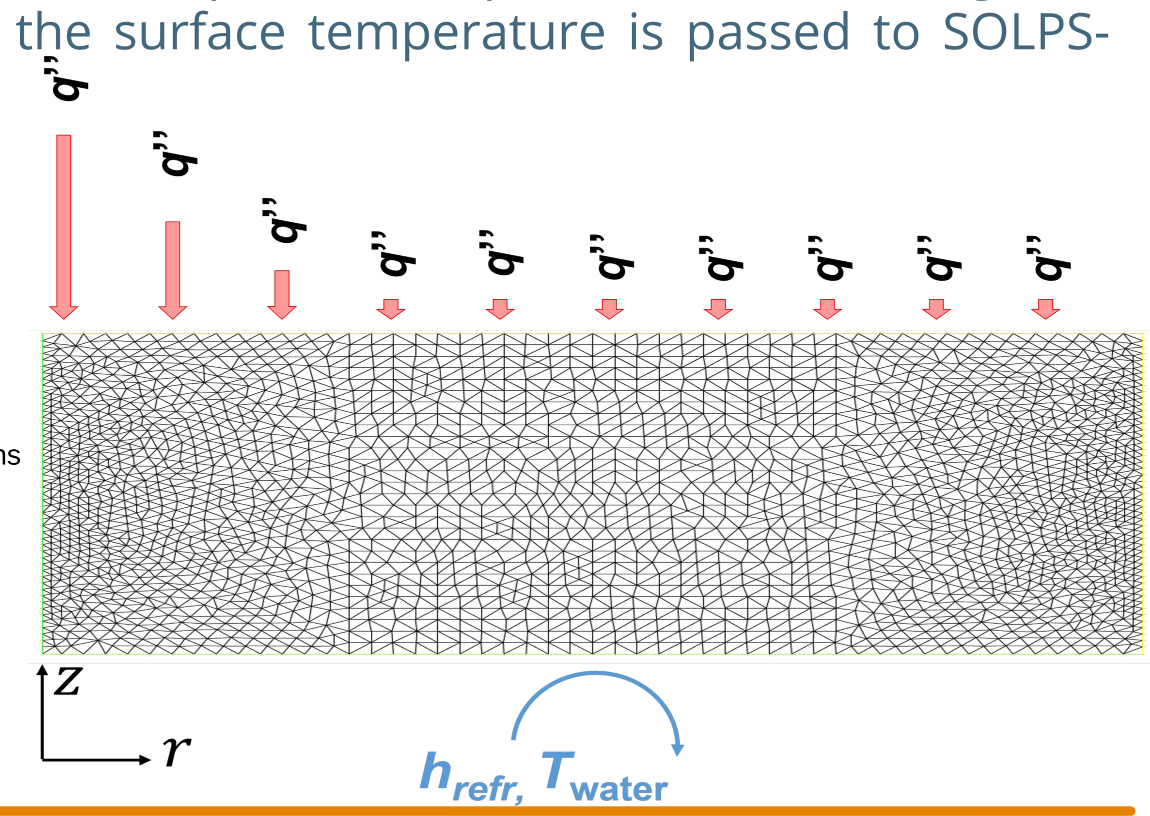
Fig. 3: Electron temperature at TS target position (z=0m) at two neutral pressures. Solid line is SOLPS-ITER simulation. Data points are TS measurements.

- The discrepancy could be associated to the dependence of e.g. the recycling rate on the target surface temperature. To investigate this aspect, SOLPS-ITER is being coupled with a Finite Element Wall Model (FEWM). This will allow to compute target properties based on plasma parameters, and to transfer this information to the SOLPS-ITER simulation.

Finite Element Target Model

- The selected thermal model for the target is a flexible, fast-running 2D transient heat conduction solver based on the Finite Element method and implemented in the open-source FreeFem++ language [3].
- The specific target geometry and materials, including temperature-dependent thermophysical properties, are all accounted for. The target is a tungsten solid target of 2.5cm in radius and 1.5 cm of thickness.
- The FE model receives as input the radial distribution of the heat flux associated to plasma and to neutrals, as computed by SOLPS-ITER. Radiation load is currently neglected but could be included in the future.
- Active cooling is implemented assuming a constant temperature of 180°C at the bottom of the target.
- At each B2.5 time step, the temperature in the target is computed and the surface temperature is passed to SOLPS-ITER.

Fig. 4: FE mesh for the thermal model of a simple disk-shaped Magnum-PSI target. Boundary conditions are also schematically indicated.



Coupling with the Finite Element Wall Model

- The first step to achieve a self-consistent simulation of the plasma beam in Magnum-PSI and a target model is to compute the target distribution of temperature with the plasma fluxes computed by SOLPS-ITER.
- When heat flux is reduced due to an increase in the neutral pressure, target temperature drops to values close to the cooling system temperature (180°C).

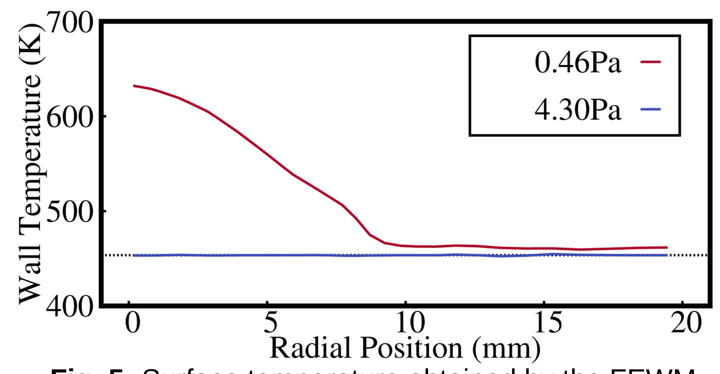


Fig. 5: Surface temperature obtained by the FEWM for two cases of neutral pressure. The reduction in plasma pressure translates to a much lower target temperatures.

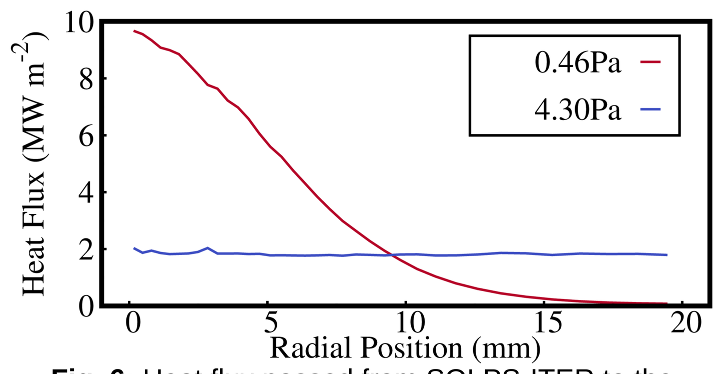


Fig. 6: Heat flux passed from SOLPS-ITER to the FEWM.

Conclusions

- SOLPS-ITER simulations reproduce Magnum-PSI experimental but still discrepancies appear, particularly at high neutral pressures..
- Coupling with a Finite Element Wall model to self-consistently compute target properties could improve these results.
- Validation of these results with a refined target model to match Magnum-PSI experiments will be performed.
- Next step is to increase the information passed back to SOLPS-ITER: evaporation flux, recycling parameter...

References

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