

SOLPS simulation of TCV divertor leg length studies

M. Wensing¹, H. De Oliveira¹, B. P. Duval¹, O. Février¹, A. Fil², D. Galassi¹, R. Maurizio¹, H. Reimerdes¹, C. Theiler¹, C. K. Tsui^{1,3} K. Verhaegh^{1,2}, M. Wischmeier⁴,
the EUROfusion MST1 team⁵ and the TCV team⁶

¹ EPFL - Swiss Plasma Center (SPC), Lausanne, Switzerland

² University of York - Plasma Institute, York, United Kingdom

³ University of California San Diego (UCSD), San Diego, United States

⁴ Max-Planck-Institut für Plasmaphysik, Garching, Germany

⁵ See the author list of H. Meyer et al., Nucl. Fusion 57 (2017) 102014

⁶ See the author list of S. Coda et al., Nucl. Fusion 57 (2017) 102011

This contribution uses TCV experiments with varying divertor configurations to investigate the particle- and heat cross-field transport within the scrape-off layer, which greatly determines the peak heat flux on the plasma-facing components. The proximity of expected peak heat fluxes to the material limits for ITER raises the necessity of obtaining a quantitative understanding of the mechanisms that determine the heat flux profiles on the divertor plates. Target heat flux profiles are often described by a truncated exponential profile with a decay length λ convoluted with a Gaussian of width S , which are interpreted as broadening due to diffusive transport upstream and in the divertor regions, respectively [1].

It is shown that an increase of the poloidal divertor leg length L_{div} (\sim factor 3) leads to an unexpected increase of λ , while having little effect on S [2]. The aim of this study is to reproduce the experimental findings quantitatively using the SOLPS code package.

Experimental setup

The TCV tokamak with its 16 poloidal shaping coils provides unique capabilities for studying the effect of divertor geometry on target heat flux profiles. Large variations in divertor leg length L_{div} , flux expansion and flux flaring have been achieved. The studies were performed with plasmas at comparable core condition ($I_p = 210$ kA, L-mode) in forward field. In-

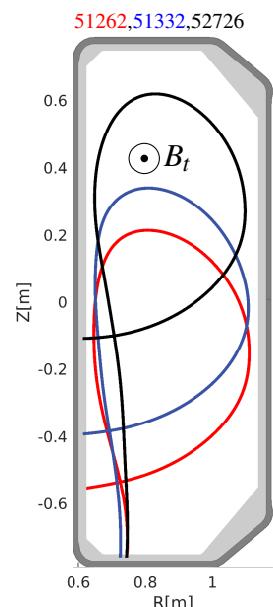


Figure 1: TCV leg length scan, ($L_{div} = 21$ cm, 36 cm, 64 cm)

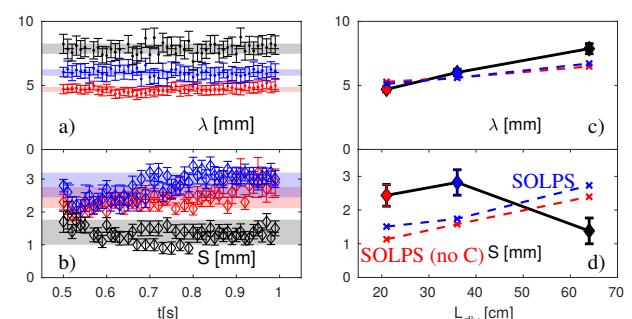


Figure 2: a,b) Time evolution of λ and S inferred from infrared thermography during the stationary phase of the discharges, c,d) time-average over the stationary phase.

frared thermography yields the heat flux profiles at the targets (Fig. 2a,b). For each 10 ms interval during the stationary period of the discharges λ and S were obtained from profile fits (Fig. 2c,d). By taking the time average over the stationary phase of the discharge the effect of fluctuations from the profile shape are ruled out. The resulting error bars are obtained from the standard deviation of the time traces (Fig. 2c,d). λ increases linearly with L_{div} , whereas S does not follow a clear trend. Similar results have been reported using heat flux profiles inferred from Langmuir probes [3].

Physics model and simulation setup

The SOLPS-ITER code package couples the B2.5 fluid model, a Braginskii solver for ionic species and electrons, and the Eirene neutral model, in which a Monte Carlo method is used to describe the atomic physics and even introduce molecular reactions to the model. The computational fluid grid is based on the magnetic equilibrium reconstruction of the experimental discharges (Fig. 3). The Eirene grid extends across the poloidal plane excluding only the inner core boundary of the fluid grid and is not shown for better visibility. The simulations were carried out with plasma species deuterium D and carbon C.

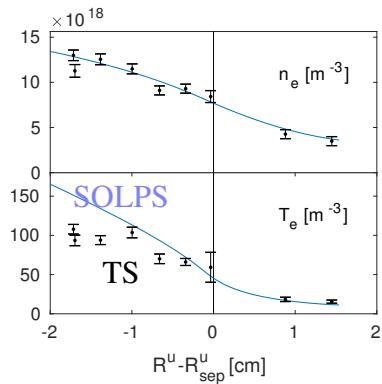


Figure 4: Comparison of upstream simulation profiles

In all cases the power crossing the core boundary was set to 180 kW, such that P_{Sol} is approximately equal to the experimental estimate while it may vary by $\sim 1\%$ in the different simulations (maximum variation ≈ 4 kW) due to marginally different core properties. At the same time, the upstream density can be controlled to a precision better than 1% in the cases studied here. Due to the numerical issues that are involved when running the code with activated drift terms, these were switched off for this study. Future work will aim to relieve this constraint.

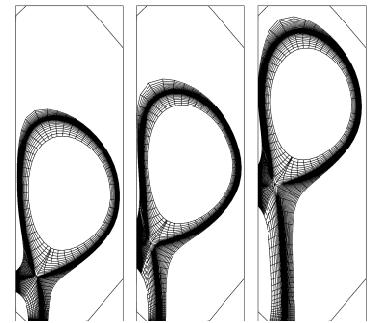


Figure 3: Simulation grids for the fluid solver based on the experimental magnetic equilibrium reconstruction

The deuterium content in the model is set by gas puff feedback. The gas flux is controlled such that the density at the outer midplane matches the experimentally obtained value ($n_e^{sep,omp} = 8 \cdot 10^{18} \text{ m}^{-3}$). Carbon is introduced by physical and chemical sputtering on wall elements. The recycling coefficients for ions and neutrals are chosen to be 99% for deuterium on all wall elements, thus enabling wall pumping. Using this setup, realistic gas puffing rates ($\sim 10^{21}$ atoms/s) are obtained.

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Transport studies

The spatial dependence of cross-field transport is investigated by rescaling the transport coefficients in certain regions (Fig.5). In the absence of a physics model for the cross-field transport, the first attempt consists in using spatially uniform transport coefficients. These are chosen to obtain good agreement with density and temperature profiles from Thomson scattering ($D_{\perp} = 0.5 \text{ m}^2/\text{s}$, $\chi_{i/e,\perp} = 0.7 \text{ m}^2/\text{s}$, Fig. 4).

The strongest dependence on the outer target heat flux shape parameters (λ, S) is found for variation of the particle diffusivity D_{\perp} , whereas the heat conductivities $\chi_{e/i,\perp}$ play only a minor role for the profile shape (Fig.6). For increasing values of L_{div} the simulation always shows increasing values of both parameters λ and S , which agrees with the experimental trend for λ (see Fig. 2c), but is less clear for S . Interestingly, λ was found to stay constant in previous studies performed with SOLEDGE2D [3]. The main difference, in the otherwise similar simulations, is i) the introduction of carbon and ii) the lack of main chamber recycling in SOLPS. By removing carbon from the simulation i) was ruled out (see Fig.2b)). At this point, it is unclear if the effect of main chamber recycling is indeed the cause for the deviation in the studies.

Previous studies with turbulent simulations [3] indicate that the transport in the divertor's common flux region (CFR) is enhanced with respect to the private flux region (PFR). This asymmetry is expected regarding the magnetic curvature (unfavorable for CFR and favorable for PFR). To test the hypothesis, asymmetric divertor transport was introduced to the SOLPS cases: the cross-field transport parameters are diminished in the PFR (Fig. 5b) or enhanced in the CFR (Fig.5c). In all other regions the transport coefficients were kept

constant ($D_{\perp} = 0.5 \text{ m}^2/\text{s}$). The target profiles (n_e, T_e, j_{sat} and q_{perp}) can be matched with reasonable accuracy (Fig. 7c,d). Indeed, the introduction of enhanced transport in the CFR moves the simulation profiles closer to the experimental measurement. However, the experimental un-

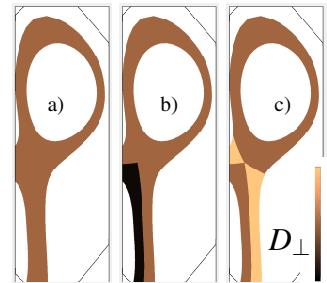


Figure 5: Investigated divertor transport profiles

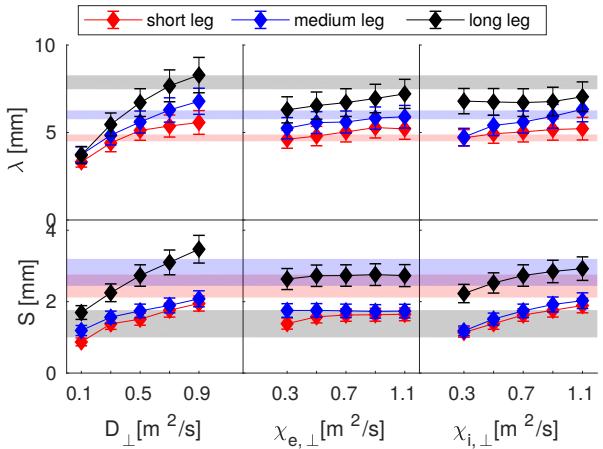


Figure 6: Effect of variation in spatially uniform transport parameters on the outer target heat flux shape parameters λ and S . The different leg length are indicated in their respective colors, the colored horizontal bars indicate the experimental values.

certainties and the inconsistency between infrared and Langmuir probe data, do not allow to exclude one of the simulation profiles from the consideration.

The upstream density and temperature profiles are unaffected by changes in the divertor cross-field transport (variation of factor 10), as long as the upstream transport is fixed (Fig. 7a,b).

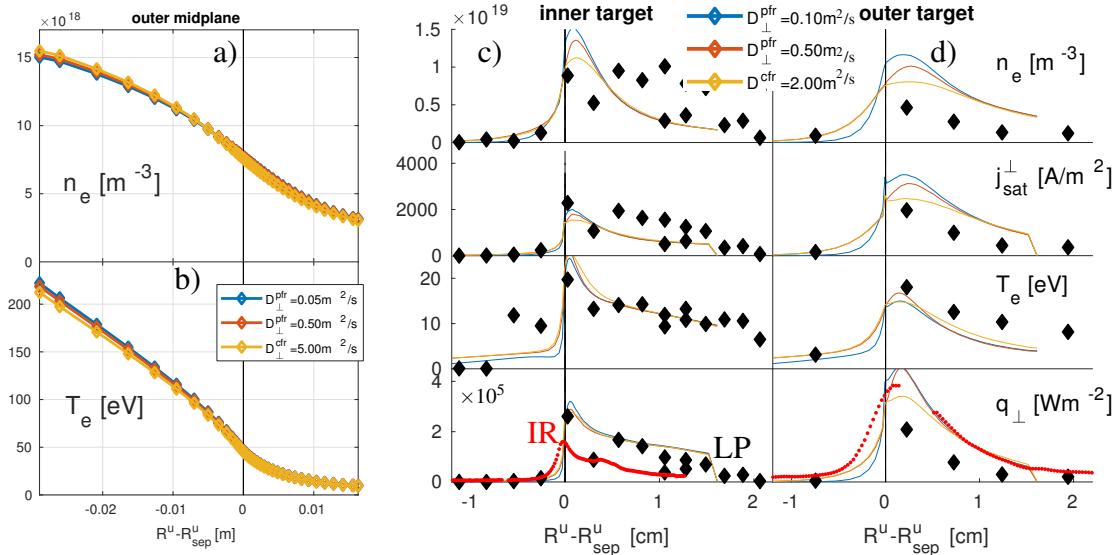


Figure 7: Comparison of simulations a,b) outer midplane, c) inner target and d) outer target profiles for the medium leg case.

Summary

Strong variation in the divertor leg length shows that λ increases with L_{div} while the trend for S is less clear [2][3]. Using the SOLPS-ITER code package major features of the experiment are reproduced. Among the different cross-field divertor transport profiles studied, no impact on the upstream profiles is found. The use of constant transport parameters already shows similar trends for λ as found experimentally. The introduction of enhanced divertor transport in the CFR yields improved comparison to target profiles.

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