Effect of the recycling profile on the SOL turbulence in the FT-2 Tokamak

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Introduction The Scrape Off Layer (SOL) dynamics determines the out flux of particles onto the plasma facing components and the influx of impurities and plasma fuel into the plasma core region. Both these processes have to be understood well for the realization of the future fusion reactors as a clean energy source. The most compelling way to study the transport process in the SOL region is by using gyrokinetic based simulation codes such as ELMFIRE [1]. In this work, the SOL dynamics in the FT-2 tokamak is studied by using the latest version of the ELMFIRE code. Both the heat and the particle transport in the SOL of the FT-2 tokamak is controlled by the properties of the sheath at the wall and limiters. In this regime (called the sheath-limited regime), the particles are ionized deep inside the LCFS region. Though the number of ionization that takes place in the SOL region will not be affected by the presence of gas puffing, there will be toroidal and poloidal asymmetry in the recycling profile of the plasma particles in the SOL region. This can be evident from the fact that the latest study [2] using only the radial recycling profile does not agree well with probe measurements in the SOL of the FT-2 tokamak. Thus, a small change has been done in the ELMFIRE code to have radial and toroidal dependency in the recycling profile and its effect on the SOL physics is studied. Additionally, simulation results are compared with movable Langmuir probe measurements.

Code details The recent version of the ELMFIRE code [3] use the Logical Boundary condition (BC), which act as a high velocity ion-electron filter to mimic the sheath conditions. The BC is applied not only to limiters but also to the wall, as it also receives ions and electrons due to the cross-field transport. When a gyroring of the particle touches a limiter/wall, it is filtered out from the simulation domain based on the BC. Since the potential is set to zero at limiters/wall, the quasi-neutrality condition is used till the Last Closed Flux Surface (LCFS), while the quasi-neutrality is used till the wall for toroidal sections which do not contain any limiters. The limiter occupies a full toroidal section in the simulation grid and extends radially from LCFS (a) to wall (a_w). The plasma particles are recycled uniformly between the region a_w -2cm and a_w in the radial direction and on one side of poloidal limiters in the toroidal direction. The temperature of the recycled plasma particles is equal to the wall temperature.

Simulation setup The FT-2 discharge used for the simulation is similar to the one in [4].

There are two limiters used in the simulation and they are separated by 180 degree in the toroidal direction. The simulation lasted 70 μs and simulation profiles were averaged over the last 20 μs in the saturated phase. The simulation uses non-uniform grid size in the radial and the poloidal directions. The minimum size of the grid in the radial direction is 0.08mm and the maximum number of cells in the poloidal direction is 400. There are 16 cells in the toroidal direction and two cells are taken by limiters.

Results The first and most important effect of the recycling profile on the SOL physics is to check if profiles in the saturated phase matches input profiles used in the simulation. The figure 1 shows that the density and temperature profiles are consistently higher than the initial profiles in the radial recycling region which is at least partly due to profile relaxation which is always present in full-f simulations if sources and sinks are not balanced. This also explains why electron temperature increases even though the temperature of the recycled particles is $T(a_w)/6$ which is considerably lower than the temperature of the particles near the LCFS region.

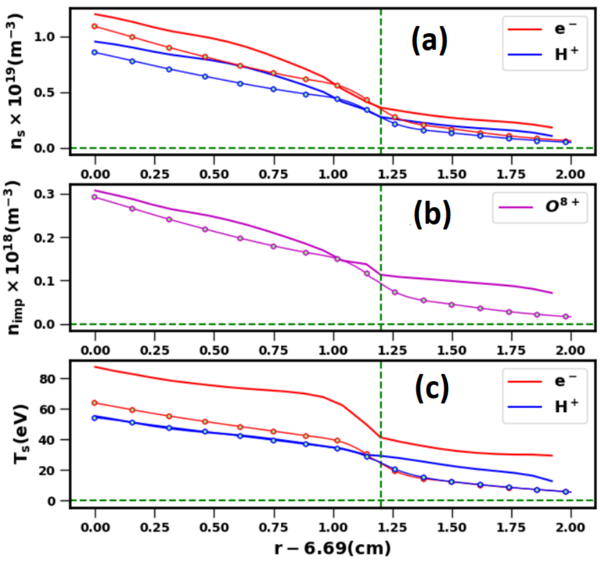

Figure 1: Flux surface averaged a) particle densities of ions and electrons, b) impurities and c) temperatures in the radial recycling region. Lines with diamonds indicate the initial profiles. LCFS is shown as a green vertical dashed line.

To understand the impact of uniformly recycling the particles 2cm from the wall, radial profiles of the density and temperature of the current simulation is compared with the previous simulation study where the recycling profile has only radial dependency and is based on the experimentally measured neutral source which had wider extent than in present work [2]. From figure 2, it can be inferred that the rise in the density profile is caused due to the recycling of particles uniformly between a_w-2cm and a_w. The rise in the electron temperature is also seen in the previous simulation study which necessitate further investigation in profiles relaxation in a simulation.

The recycling profile does not have any negative impact on the radial electric field (E_r) as can be seen in the figure 3. The E_r follows the neoclassical electrical field given by the H-H (Hinton-Hazeltine) estimate [5] within the LCFS region. It follows the -3∇T_e, as dictated by the sheath physics [6] in the SOL.

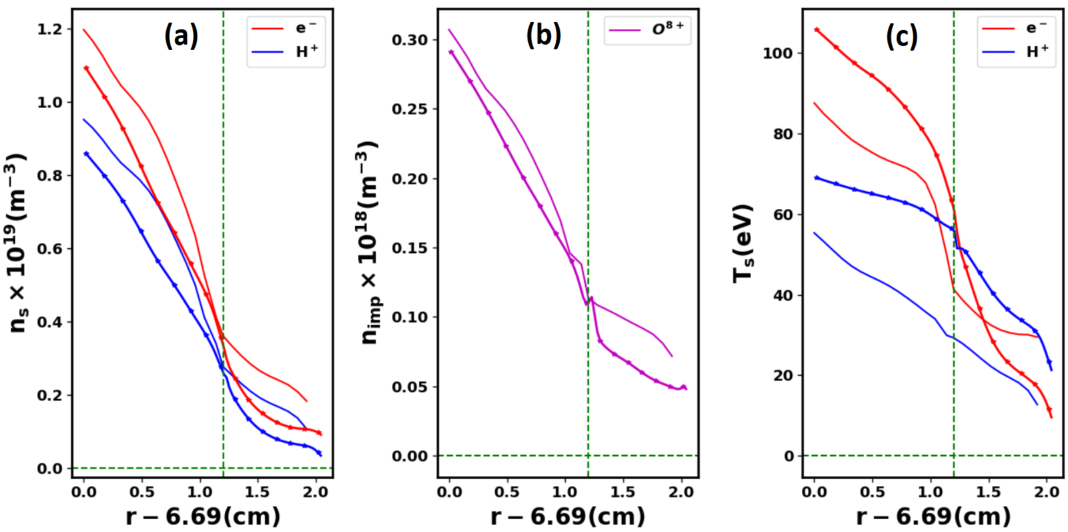

Figure 2: Flux surface averaged a) particle densities of ions and electrons, b) impurities and c) temperatures in the radial recycling region. Lines with triangles indicate the simulation with wider radial recycling without toroidal dependence. LCFS is shown as a green vertical dashed line

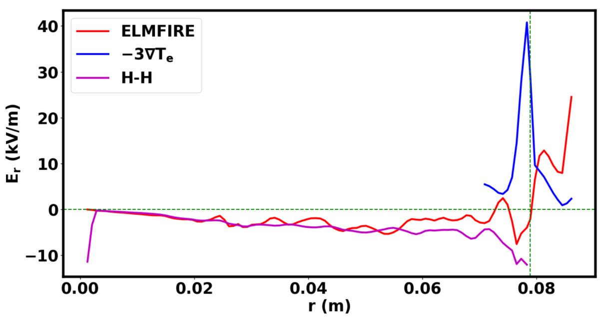

Figure 3: Radial profiles of the electric field. The LCFS is shown as a green vertical dashed line.

While the simulated radial electric field reaches zero at the LCFS, the term -3∇T_e have a peak inside the LCFS and then drop down to zero after crossing the LCFS. But near the sheath, both the simulated and the sheath electric fields becomes positive.

The comparison shown in the figure 4 implies that the temperature and density predicted by the simulation are not in agreement with the Langmuir probe measurements in the SOL region at selected poloidal angles.

When ions accelerate towards the sheath, their velocities reach the value of sound speed at the entrance of the sheath. In the figure 5, magnitude of the ion mach number exceeds the value of 1 when approaching the limiter and thus satisfies the Bohm criterion. The value of ion mach number is around -0.5 at the top poloidal section while it is around -2.0 at the bottom section. This can also be seen in figures 5b and c, where the value of the ion mach number is less than 1 in the top section.

Conclusion Changes made in the recycling profile has affected the formation of radial density and temperature profiles and value of the ion mach number in the simulation. Thus as a next step, it is recommended to have a radial recycling profile measured from the experiments and have toroidal dependency just near limiters and study its impact on the SOL physics.

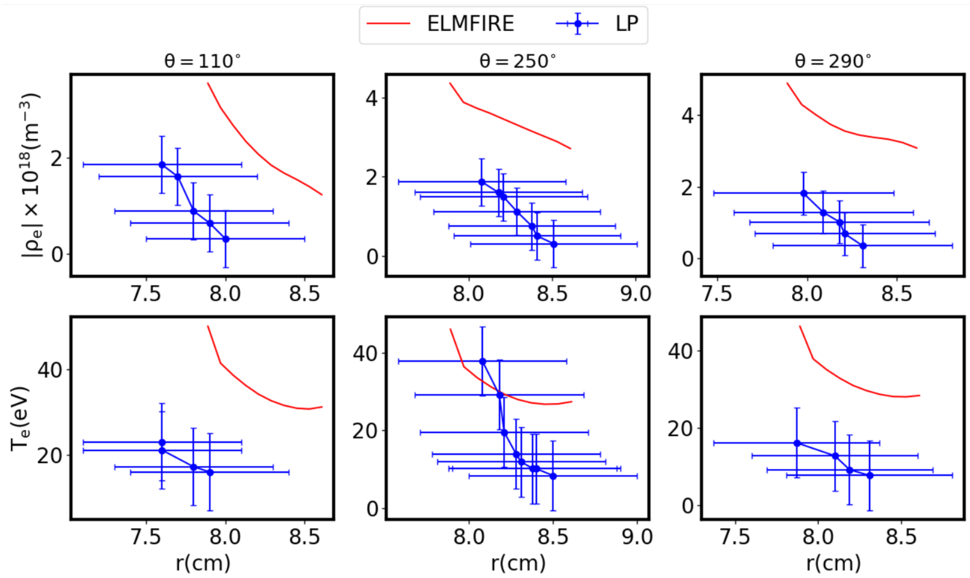

Figure 4: Comparison between electron temperature and density between ELMFIRE results and Langmuir probe measurements in the SOL.

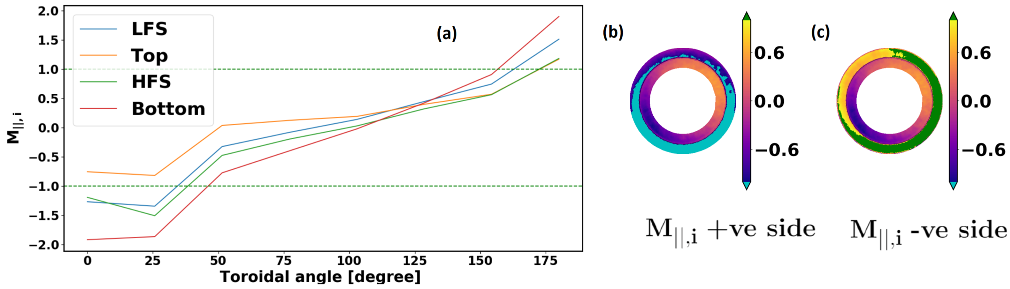

Figure 5: (a) shows profiles of the parallel Mach number in the SOL in the toroidal direction, averaged over four different poloidal positions: Top, Bottom, HFS, and LFS. b) and c) are poloidal sections of $\mathrm{M}_{||,\mathrm{i}}$ *at the position of a limiter, on either side. Dashed lines shows the value of* $\mathrm{M}_{||,\mathrm{i}} = \pm 1$.

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