ECWC experiments and modeling on TCV

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During the first stage of ITER operation (PFPO-1), Electron Cyclotron Wall Conditioning (ECWC) will be the only available conditioning technique in the presence of a toroidal field. The limited experience with this technique calls for dedicated modeling and experiments to ensure that ECWC can be an efficient conditioning tool for ITER.

The TOMATOR 1D hydrogen helium plasma simulator numerically describes the evolution of currentless magnetized RF plasmas in a tokamak and was initially benchmarked with experimental data from TCV Helium plasmas to determine the transport coefficients used in the diffusion-convection-reaction equation of the simulation [2].

Several ECWC experiments were performed in TCV to study the influence of the heating power, the magnetic field and the neutral pressure on the plasma parameters and the particle fluxes to the wall. In this paper, the density profiles, measured with the Far Infrared Interferometer, are compared to the modeling with the TOMATOR 1D simulator to benchmark the code also for deuterium plasmas. The particle fluxes are measured with Langmuir probes. They give us an indication of the amount of particles at the wall at different locations in the machine.

Model description The model used for the simulations is based on transport equations, deduced from the standard continuity and heat balance in cylindrical slab geometry, assuming a Maxwellian energy distribution for all particle species. A description of the included collisions, mostly based on the EIRENE HydHel database, can be found in [1].

The inhomogeneous magnetic field in a tokamak leads to a vertical electric field by virtue of particle drifts, resulting in an outward convective flow due to the $E \times B$ drift. The convection coefficient is implemented as being dependent on the plasma temperature and magnetic field with a tunable convection parameter f_V as shown below. The radial diffusion D_r is anomalous and implemented with a tuning parameter f_D, taken as 1/16 by Bohm and experimentally set at 0.21 by Spitzer. It is dependent on the collision frequency of the ions $\nu_{c,i}$, the Larmor radius of the ion at the thermal velocity r_i and the ion mean free path λ_i, while B_r and B_φ are the local radial and toroidal components of the vacuum magnetic field.

$$V_r = f_V \cdot \frac{(T_e + T_i)}{B_r} \qquad D_r = \frac{1}{3} \cdot f_D \cdot \nu_{c,i} \cdot \left(r_i + \lambda_i \cdot \frac{B_r}{B_\varphi} \right) \cdot \lambda_i \tag{1}$$

The model takes as input the machine size, the components of the vacuum magnetic field, the heating power (assuming multi-pass absorption) and the neutral pressure (from measurement). It gives as output the temperature and density profiles which can be compared with experimental data and the vertical and radial particle losses.

Transport coefficients in Helium Recently, small improvements have been applied to the Tomator-1D code, concerning collision rates, edge conditions, power deposition and neutral fluxes. To compare the present code with previous result of [2], the Helium discharges simulations have been rerun, with an additional lower power pulse. The Power scan is performed [shots #51513-51517] at 82.7 GHz (X2) with gyrotron G6 and the upper launcher ($\theta = -10°, \phi = 5°$) and a toroidal magnetic field $B_t = 1.54\ T$ and no vertical component ($B_v = 3.5\ mT$). The convection and diffusion parameters f_V and f_D are tuned to match the experimental density profile. The diffusion parameter f_D shows a clear downward trend with rising power (and density, shown on the right axis), while the convection parameter f_V shows a clear upward trend (figure 1).

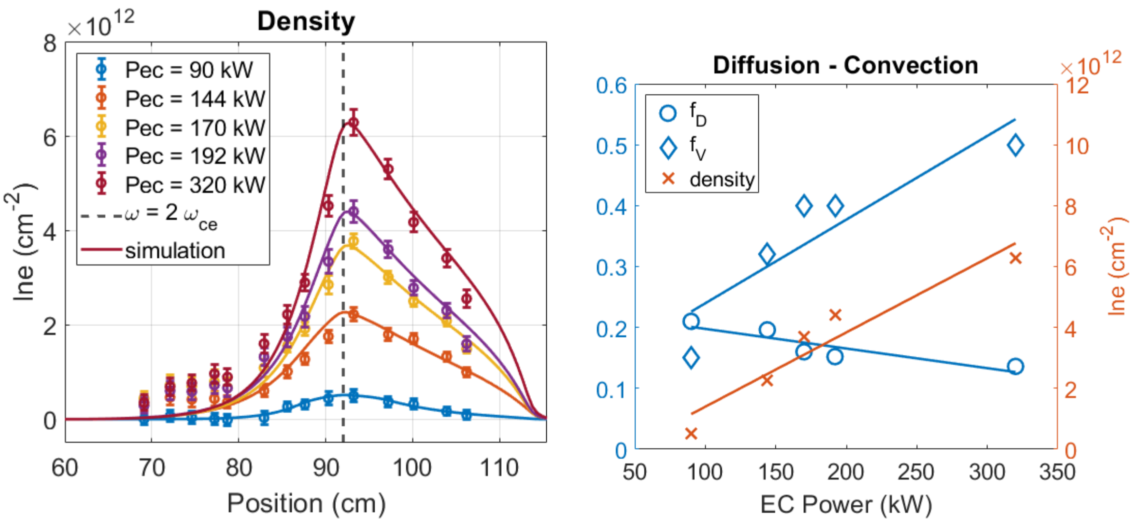

Figure 1: Density profiles from experimental data and simulation for TCV shots #51513-51517

Transport coefficients in Deuterium To estimate the diffusion and convection coefficients in Deuterium ECRF plasmas, the code is benchmarked with experimental data from TCV. A Power scan is performed [shots #72541&72543] at 82.7 GHz (X2) with the equatorial launcher

($\theta = 8°, \phi = 90°$), a toroidal magnetic field $B_t = 1.54\ T$ and a vertical component $B_v = 7.55\ mT$ (figure 2). The convection and diffusion parameters f_V and f_D are again tuned to match the experimental density profile. The 3 power levels show a similar value for diffusion ($f_D = 1.27 \pm 0.15$). A value which is 6.5 times higher than for Helium. There is however a big difference for the convection between the two shots:

- #72541: $f_V = 10.0$
- #72543: $f_V = 3.5$

This is probably due to a difference in the neutral pressure.

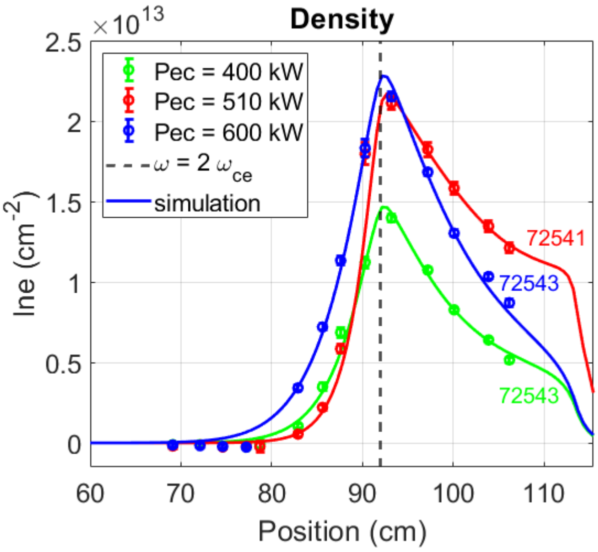

Figure 2: Density profiles from experimental data and simulation for shots #72541&72543

Conclusion The transport parameters can be determined in function of the injected power for TCV. They can be used for future simulations. Similar work is being done on TOMAS and ASDEX and is foreseen for JT60-SA, to include the machine size dependencies on the transport coefficients. This will allow extrapolation to ITER.

Langmuir probe measurements The technique of ECWC is used for cleaning purposes in the presence of a magnetic field. However an important issue is still open for the first stage of ITER operation (PFPO-1): impurity removal e.g. after mitigated disruptions by the DMS system. Due to the radial outward plasma drift inherent to the simple toroidal field configuration in ECWC plasma, the highest ion flux is expected at the LFS wall.

To reach the HFS of the machine with a large particle flux, we have to counter this outward drift. Adapting the magnetic configuration can direct the plasma from the place where it is created, to the desired area [3]. Several ECWC experiments were performed in TCV to study the influence of the magnetic field configuration on the particle fluxes. These fluxes are measured with Langmuir probes.

The implementation of a pure vertical field (shot #72572) shows that the HFS can not be reached (figure 3). Sweeping the Electron Cyclotron Resonance ECR layer from the LFS to the HFS during this shot, reduces the particle flux at the LFS and increases the intensity at the top of the device.

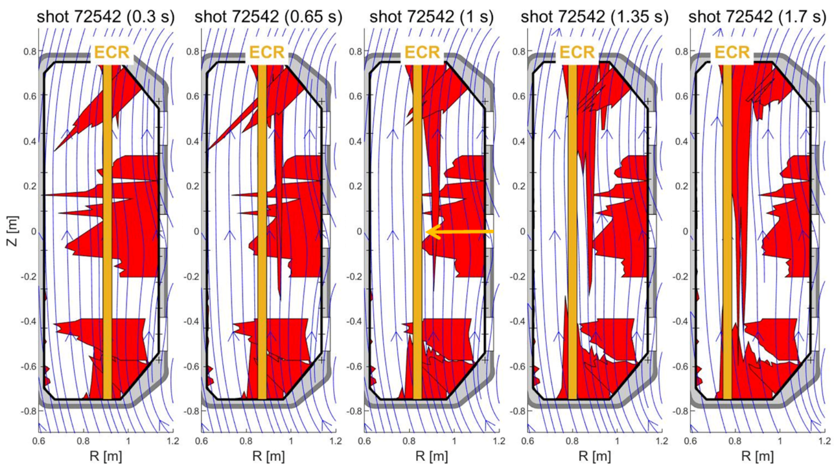

Figure 3: Langmuir Probe measurements for shot #72542

The implementation of a quadrupole magnetic field (shot #72573) shows that the HFS can be reached with a small particle flux close to the magnetic null point. Sweeping the ECR layer to the HFS increases the particle flux there (figure 4).

Using specific magnetic field configurations, the flux can be directed to different positions at the HFS and the divertor. Shot #72575 shows an example where the null point is situated close to the HFS at the bottom of the machine. It is clear that the plasma is created in the center of the machine and directed from the point of creation to the magnetic null point, following the field lines. This has been confirmed by camera images [4].

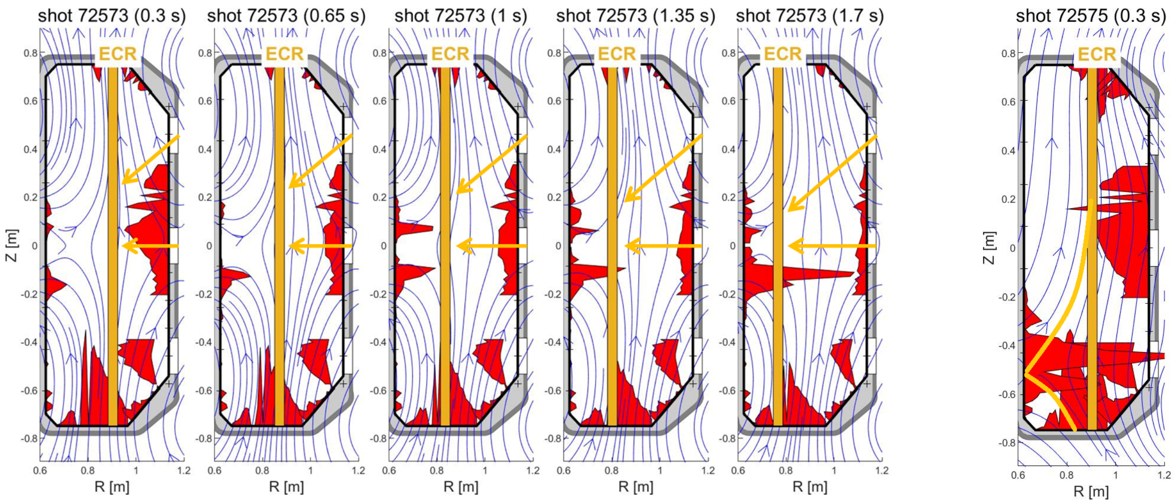

Figure 4: Langmuir Probe measurements for shot #72543 and #72545

Conclusions The poloidal magnetic field map and the position of the resonance, determined by the EC frequency and toroidal field strength, plays an important role in the location and the intensity of the particle fluxes. The HFS of the machine can be reached with a high particle flux and this flux can be directed to different positions at the HFS and the divertor in TCV.

References

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