Impact of the carbon and tungsten wall materials on deuterium recycling and neutral fuelling in JET using EDGE2D/EIRENE

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1. Introduction. To investigate the impact of full metal walls on the operational boundaries of next step devices, the former, all-carbon plasma-facing components (PFCs) of JET (JET-C) were replaced with a full metal ITER-like wall (JET-ILW), with beryllium main chamber limiters and tungsten divertor [1]. This refurbishment is anticipated to have a strong impact on the fuel recycling processes, where deuterium particles impacting material surfaces are either reflected as atoms, with a considerable fraction of the impact energy, or implanted in the material. These implanted particles can be further thermally re-emitted as molecules into the plasma. In steady state conditions, particles will be implanted and re-emitted with equal rates, thereby, leading to particle balance in the plasma. The reflection process depends on the impact angle, energy, and on the mass ratio between the projectile and substrate. Tungsten with its high mass is predicted to lead to higher particle and energy reflection for recycling species [2], compared to carbon surfaces. Hence, one of the fundamental consequences expected, is the increase of atomic versus molecular fraction in the recycling fluxes [3], which is expected to impact the divertor conditions, plasma fuelling, core charge exchange (CX) losses, and the pedestal width and height. The beryllium surfaces used in the main chamber may also have different fuel recycling properties compared to the carbon surfaces, since the reflection coefficients vary strongly between mass ratios 4.5 for beryllium and 6 for carbon, assuming deuterium fuel particles [2]. The surface chemistry differences between beryllium and carbon might also play a role.

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[i] *See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA FEC 2012, San Diego, USA.*

In JET-C, molecules were observed to dominate the recycling flux with a fraction of about 70 – 90 % [4]. Similar observations have been reported on deuterium recycling on graphite surfaces in TEXTOR [5]. In JET-ILW, on the other hand, a larger contribution of atoms versus molecules in the divertor plasmas were measured [3].

In this study, the multi-fluid code EDGE2D/EIRENE [6, 7, 8] was employed to investigate numerically the impact of the PFC materials on the edge neutral sources in JET for unseeded L-mode plasmas (2.5 T / 2.5 MA / ~ 3 MW) in V5/Stack-C and vertical target (VT) configurations [9] as well as for the inter-ELM phase of unseeded H-modes (2.7 T / 2.5 MA / ~ 16 MW) in HT3R configuration [10] (Fig. 1a). In the simulations the power across the core boundary was obtained from the core power balance: 2.2 MW (L-mode), 10 MW (steady-state inter-ELM H-mode). By neglecting impurities, the simulations are conducted using exactly the same input parameters for both JET-C and JET-ILW. In the H-mode simulations, such an approach, however, neglects the strong reduction in the unseeded H-mode pedestal confinement in JET-ILW compared to JET-C [11]. Therefore, while the majority of the H-mode simulations are conducted assuming JET-C like pedestal based on [12], a few simulations in the JET-ILW are run with reduced pedestal temperatures corresponding to the actual measurements by increasing the pedestal conductivity by a factor of 2.

2. Results. The simulations show that in JET-ILW, atoms dominate the recycling flux with a fraction of 60 – 80 %, whereas, in JET-C, molecules dominate with a fraction of 55 – 70 % (Fig. 1b). The values for JET-C are qualitatively consistent with earlier observations documented in [4, 5]. The absolute magnitude of the atomic fraction is, however, a factor of 2 higher in these simulations. This discrepancy is presumably a result of the limited impact angle range, determined by the calculation grid, in the simulations. Energy reflection of the order of 50 – 60 % for JET-ILW and 20 – 35 % for JET-C were simulated (Fig. 1c).

Although a higher atom fraction is predicted for JET-ILW, the core neutral influxes are the same within 10 % between the JET-C and JET-ILW simulations (Fig. 1d). The figure 1d also shows that the variations between the simulated configurations are much stronger than between the wall materials. Therefore, in the simulations, the geometric effects and plasma conditions dominate over the substrate effect. To further understand the similarity in the fuelling profile, the source distribution of the core fuelling neutrals would need to be known. Unfortunately, this information was not available in the present simulations. Hence, the core fuelling distribution is analysed instead. The neutral flux into the core is divided into two domains: x-point fuelling represented core fluxes below Z=-1m, and main chamber fuelling represented by core influxes above Z=-1m.

It is observed that the neutral influx to the core is dominated by the main chamber contribution in most of the plasmas. Only in the lowest density L-modes and detached VT simulations are the 50 % levels reached with the x-point fuelling fraction. Therefore, it seems probable that the core influx is dominated by the main chamber sources as well. However, in order to validate this hypothesis, the code need to be updated to store the source distribution of the core fuelling neutrals. This will be assessed in subsequent studies.

Similarly to the core neutral influxes the core CX power losses vary within 5 – 20 % only. In the L-mode simulations, the CX losses are the same approximately within 5%, in plasmas with comparable recycling flux. In the inter-ELM H-mode simulations, on the other hand, the CX losses in the JET-ILW are 20 % higher compared to those in JET-C in comparable recycling, assuming JET-C like pedestal confinement. If the pedestal temperature in the simulations is reduced down from the JET-C relevant values of about 800 – 1100 eV to the JET-ILW relevant values of about 500 – 700 eV, the core CX losses in the JET-ILW simulations are dropped down to approximately 40 % below the simulated JET-C values (Fig. 1f). The reduction of the CX losses occur due to the combined effect of 20 % lower core CX rate as well as a factor of 1.5 lower ion pedestal temperatures. The CX rate is reduced solely due to a 20 % increase in the ionization versus CX ratio due to the decreased temperature, while the neutral currents to the core remain the same within 5 % (Fig. 1e). Hence, in similar pedestal temperature, the core CX losses seem to be slightly (10 – 20 %) higher in the JET-ILW H-modes, and the core CX losses drop strongly with reduced pedestal temperature. In the overall power balance in the simulations the 10 – 20 % increase means that the CX power loss fraction increases from 4 – 8 % to 5 – 10 %. Therefore, changing from the JET-C to the JET-ILW wall materials, the core neutral influxes and CX power losses are not changed significantly.

The simulations here were conducted in steady state inter-ELM conditions. Therefore, the impact of the deuterium recycling properties to the post ELM recycling, and pedestal recovery, and the subsequent impact on plasma performance remain a subject for further studies.

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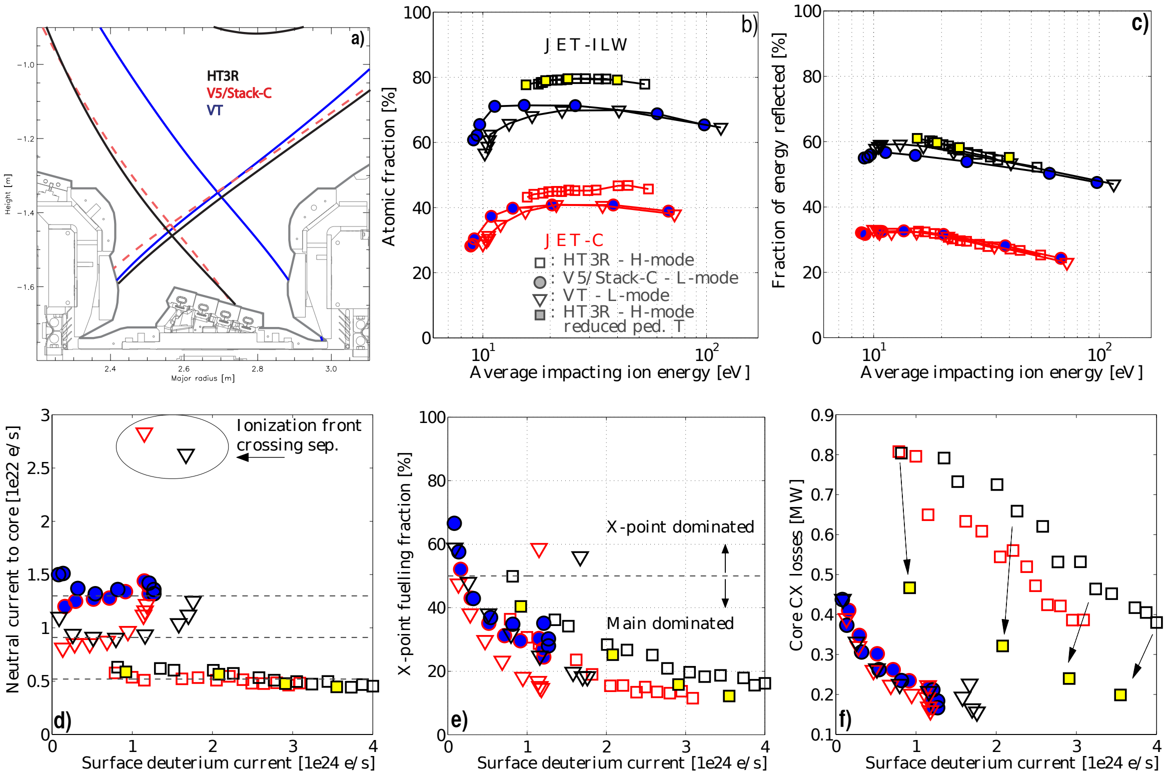

Figure 1: a) Magnetic topologies in the divertor in the simulated plasmas: HT3R (black), V5/Stack-C (Red), and VT (Blue). b-c) the simulated effective particle and energy reflection coefficients, d) neutral deuterium gross current crossing last closed flux surface, e) the fraction of core neutral influx crossing the separatrix below Z=-1m, and f) CX-power losses inside separatrix. Red symbols represent the carbon wall simulations and black symbols the ITER-like wall simulations. The open squares stand for the standard HT3R inter-ELM H-mode simulations, the filled circles for the V5/Stack-C L-mode simulations, the open triangles for the VT L-mode simulations, and the filled squares for the reduced pedestal temperature H-mode simulations.