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Edge Transport Characterisation of Hydrogen and Helium Plasmas in the TJ-II Stellarator

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1. Introduction.

The Spanish stellarator, TJ-II (R=1.5m, a < 0.22m, B_0 <1 T) has been recently operated under a broad range of scenarios, including changes in the working gas (H_2 *vs* He), microwave heating power (100-600 kW, two independent lines at 53.2 GHz, 2nd harmonic X-mode) and plasma-wall interaction conditions (wall conditioning, poloidal *vs* toroidal limiter) [1]. Similar central plasma values have been achieved for both (H, He) plasmas ($ne_0<1.7.10^{13}$ cm^{-3}, $Te_0<$ 1.5 keV, total E content <1.0 kJ), and no major differences in edge parameters have been found either. However different recycling conditions for both types of plasmas were observed, and a significant dependence of particle recycling with injected power was evidenced for He plasmas [2]. These issues have shown critical in discharge control since wall fuelling plays a crucial role in the achievement of stable density values below the ECH cut-off [3]. In this work, the edge plasma parameters for the two species studied and their dependence on limiter configuration and heating power are reported. The results of the recently installed TJ-II edge diagnostics, as a thermal lithium beam and a supersonic helium beam (that provide information of plasma parameters up to r/a values of < 0.6) are reported. In addition, data from visible emission edge tomography and electrical probes are also used for the characterisation of the transport properties at the plasma periphery. A preliminary analysis of the particle and energy transport is presented. Evidence for particle confinement degradation with injected power and the presence of energy loss channels not reflected in the edge characteristics is given.

2. Plasma edge characterisation

The main features of the edge and SOL of the TJ-II plasmas have been previously described [4]. Briefly, the LCMS can in principle be defined by the intersection of the field lines with the part of the vessel surrounding the central helical coil, which acts as a helical limiter, therefore leading to the lowest possible particle and heat flux densities at the plasma facing surfaces. Alternatively, two poloidal, movable limiters [5] whose limiting efficiency strongly increases as they are inserted deep into the edge (typically up to 3-5 cm from the nominal LCMS) can be used. The SOL topology can be described by a spectrum of connection length values, which are strongly dependent on magnetic configuration and radial distance from the LCMS. Values

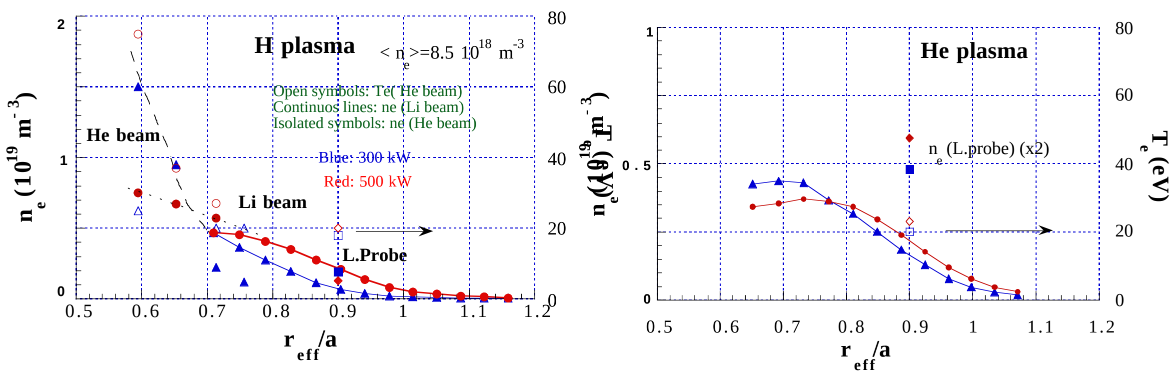


Fig. 1. Plasma edge profiles of electron density and temperature for H and He plasmas at constant density.Two cases of P_{in}. (300 and 500kW) are shown for each species.

from 2-15 m, for the helical limiter, and 20 to some hundred meters for deep insertion of the poloidal limiters have been calculated. Radial profiles deduced from Langmuir probe have experimentally confirmed such a strong enlargement of connection lengths as the limiters are inserted, and values of the SOL e-folding widths consistent with typical D_{Bohm} have been measured.

In the present studies, the TJ-II atomic beam diagnostics [2] have been applied to the characterisation of the plasma boundary of H and He plasmas under the heating scenarios above described. A thermal Li beam, located at ≈ 80 cm from the observation region, has been used for the reconstruction of the SOL and edge parameters in both types of plasmas. A 16 channel photomultiplier array allows for the continuous recording of the Li* emission radial profile. Detection of the Li* emission up to > 8 cm into the LCMS (corresponding to r_{eff}/a values of <0.7) was possible. Also from a top window, the TJ-II supersonic He beam is launched into the plasma. For the experiments here reported, pulses of 1ms were produced from the piezoelectric valve, located at ≈ 90 cm from the plasma edge. He lines at 667, 706 and 728 nm were monitored, and their spatial profile was measured in a shot to shot basis in H plasmas. Application of a collisional radiative model allowed for the reconstruction of the electronic parameters at the edge (n_e, Te). Fig.1 summarises the results for H and He discharges having the same average electron density, for two values of total ECRH injected power. In the left figure, data for both type of beams, together with data from the Langmuir probes located on the poloidal limiters, which were slightly inserted into the edge, are displayed for H plasmas. As seen, good agreement is observed among the different edge diagnostics in general. The discrepancy observed at low densities

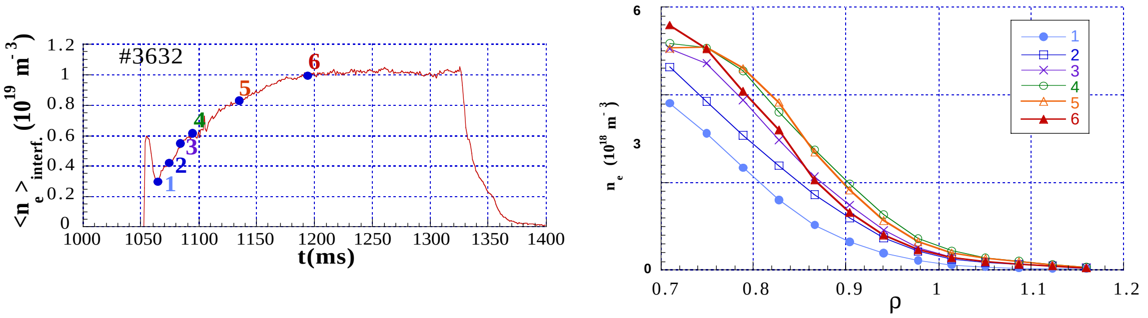
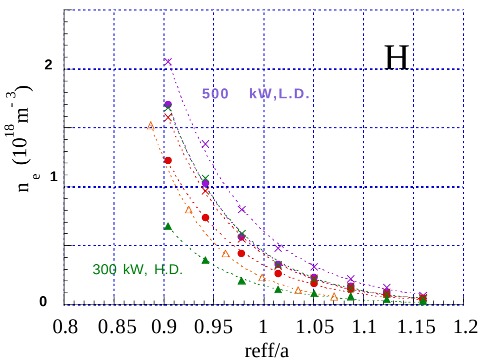


Fig 2. Time evolution of electron density profiles at the edge during density ramp-up

(He/Li beams) can be readily associated to the expected smearing effect due to the relatively long relaxation times for the electronic levels of He atoms involved and the beam velocity. Some of the main features observed in a power scan are apparent from the figure. Thus, for example, no. significant differences in electron temperatures near the LCMS are seen as the power is varied. Broader density profiles are recorded for higher injected power at constant density while small variations with average electron density were observed. Electron temperatures in the range 15-25 eV were typically measured by the Langmuir probes at the location of the poloidal limiter, which, together with the He beam data, confirm the presence of an almost flat T_e profile from ρ values > 0.6/0.7, in agreement with ECE and Thomson Scattering profiles [1]. This point has been confirmed by the reciprocating Langmuir probe diagnostic, able to provide values of edge parameters for ρ > 0.7 in a single shot. Very similar edge parameter values and features similar to those above described were found in He plasma edges, as shown in Fig.1, although only electron temperature data from the reciprocating probe were available for the present study. The behaviour of the edge density during the rise of the electron density by external puffing is displayed in Fig.2. After an initial growth, a constant radial profile is.established at the plasma periphery as the mean electron density is been raised. A similar behaviour is seen in other edge diagnostics, as the Hα monitors (see below) and the Langmuir probes thus indicating a strong evolution of the central density profile during the plasma shot.

Measurements of the density e-folding length were made by means the Li beam. In spite of the complexity of the TJ-II SOL region referred above, a single λ_n value fits the profiles under all conditions, at least for the fixed poloidal limiter radial location (ρ = 0.9) used in the power scan, as displayed in Fig.3. The λ_n values obtained for the two types of plasmas, at several heating power and electron density conditions are summarised in Table I. As seen, a weak dependence of this parameter on the experimental conditions has been detected.



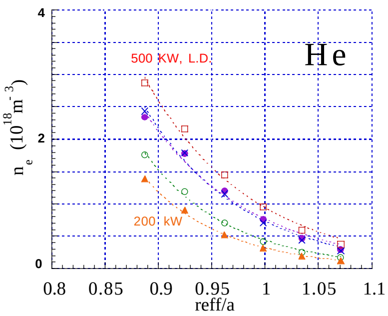


Fig.3 S.O.L density radial profiles for H and He plasmas

Emission from the edge was recorded by a photomultiplier array with the same characteristics as described above, Hα profiles were continuously recorded for a series of experimental conditions in H plasmas. He lines at the same wavelengths as used for the He beam diagnostic were recorded in He plasmas by means of a scanning mirror with a time resolution of 10 ms. While strong variations of the line intensities and their ratio were observed in the power scan for He plasmas, H plasmas showed the same shape of the line integrated Hα radial profiles for all conditions. As an example, Fig.4 shows such type of profile during a density scan similar to that displayed in Fig.2

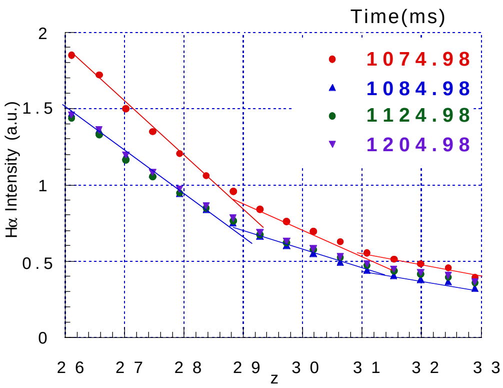


Fig.4. Hα profiles during density ramping by external puffing(Poloidal Lim. At z=29)

A basically linear rise of emission intensity with radial position can be observed, the slope suddenly changing at the radial location where the poloidal limiter (45º toroidally displaced) is located. A preliminary analysis of these profiles with a simple neutral transport model indicates thermal energies for the transport of neutrals in H plasmas. A full simulation of such transport by the Eirene code is presently underway.

3. Edge Transport and Discussion.

Although very limited information on poloidal asymmetries is presently available for the conditions here shown, some important facts on the behaviour of particle and energy transport in ECRH plasmas in TJ-II can be inferred from the experimental results above described. First of all, a clear uncoupling between the edge and central plasma characteristics exists. The

Gas	Power (kW)	Electron Density $10^{12}cm^{-3}$	λ_n SOL (mm)	D_{LCFS} m^2s^{-1}	τ_p(ms)
Hydrogen	300	8.5	13.7	0.98	14.0
	400		14.8	1.1	6.6
	500		16.0	1.3	5.0
Helium	200	5-6	15.5	0.8	7.3
	300		18.5	1.14	4.8
	400		20.0	1.33	3.0
	300	9	16.2	0.85	10.0

Table I. S.O.L.parameters for H and He plasmas and values of particle confinement time inferred from them

insensitivity of edge density to total particle content of the plasma, in one hand, and the constant values of electron temperature as the injected ECH power is increased, on the other, indicate a weak connection between the central and peripheral regions in TJ-II. The fact that the power deposition takes place in a fairly highly defined central region of the plasma implies a limited transport of energy to the plasma periphery. Assuming a negligible poloidal and toroidal asymmetry on transport coefficients, some estimates on power and particle balance can be made from the reported results. First, particle diffusion coefficients at the LCMS can be deduced under a simple slab model approximation [4]. The results, for an average Lc value of 4 m, are given in Table I. Typical D_{Bohm} values are obtained. A clear increase with injected powers can be observed, and the only comparison available for density scaling is consistent with a linear dependence. From these results and the n(a) values obtained, global particle confinement time are deduced: $\tau_p = \langle ne \rangle V_p/(D.na.S_p/\lambda)$, with V_p and S_p being the plasma volume and outer surface area, respectively. The results are also given in Table I. A clear degradation of particle confinement with injected power in H plasmas is apparent from the table. Also, similar (slightly smaller) values and tendency of τ_p are deduced for He plasmas.

A natural coupling between edge characteristics, particle and impurity behaviour and central plasma parameters is typically expected in medium sized fusion machines, such coupling being a strong function of particle and impurity mean ionisation length compared to the average plasma size. Most medium sized stellarators have indeed reported this type of behaviour [6], In the TJ-II device an due to the intrinsic topological features of the magnetic configurations and the vacuum vessel, a close contact between parts of the vessel and the plasma is produced [2,5].However, energy balance inferred from the particle fluxes and measured edge temperatures can account only for less than half of the injected ECH powers. Due to the relatively low fraction of radiated power observed in these plasmas [2], other energy loss mechanisms (such as direct high- energy particle losses by ripple trapping) must be invoked. The impact of these losses in the particle balance, and hence, in the τ_p values given in Table I, must be evaluated accordingly.

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