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ABSTRACT

The deuterium and helium dynamics in the plasma and sub-divertor regions of JET are compared during a sequence of similar pulses where 100% He gas is injected into the JET vacuum vessel, whose graphite walls were previously saturated with deuterium. After the first six He fuelled change-over discharges, only He plasma operation was performed. Following this investigation, the situation is reversed and the change-over from an initially saturated He wall is investigated when only D₂ plasma fuelling is used. The He concentration is measured in the sub-divertor with a species selective Penning gauge. Comparison of the time dependence of the divertor concentrations with those at the edge and strike point shows significant differences during the first six discharges. This difference along with a global He particle balance is used to assess the status of the wall saturation over the initial 6 - 7 He change-over discharges.

1. INTRODUCTION

Pure Helium (He) plasma operation has been proposed as a low activation phase in the initial operation of ITER. To understand the implications of this, a series of pure He experiments were performed on JET during March 2001. A comprehensive paper on the confinement physics, L-H transition threshold, and ELM transport in these He plasmas is included in this conference[1]. The experiments reported in this paper focus on the influence of the deuterium-saturated wall for the initial purity of the He plasmas and the time required to achieve high purity He plasmas. The hydrogenic inventory has previously been found to be ‘dynamic,’ that is, it changes substantially depending on the past history of particle fluxes to the wall and their energy dependence. This paper investigates the study of the core plasma-wall exchange dynamics, between the plasma and sub-divertor region of JET, for a sequence of pulses in which 100% helium (He) is injected into the JET vacuum vessel which, before the first shot (53937), is loaded with ~100% D. Using a species-resolved Penning gauge to measure He concentrations in the sub-divertor area, the dynamics of the plasma-wall exchange have been investigated by tracing the divertor concentrations over the first six change-over discharges where the concentrations change the most.

Previously, similar JET change-over experiments were performed with T and H [2], which was introduced into a D saturated wall environment. The systematic differences between the Penning measurements and the composition measured at the strike point by divertor spectroscopy were found to be a sensitive measure of the near-divertor wall saturation.

2. EXPERIMENTAL ARRANGEMENT

The JET He to D change-over experiments described here were performed with the MkII-GB (gas box” divertor configuration). The Penning gauge system [3] for measuring the He concentrations, He partial pressure, and deuterium partial pressure in the sub-divertor region is installed at a duct of the JET divertor. The He and D₂ from the divertor travels along the vacuum duct to the Penning gauge and is ionized by the Penning discharge. The light from the He and D transitions emitted by

the Penning discharge are viewed via a quartz fiber and transferred to a detection system. The details for determining He or D concentrations can be found in Refs.[4]. The He concentration is also measured via a divertor spectrometer which views the outer strike point region of the divertor. A new divertor molecular spectroscopy measurement (CD band) was utilized which also views the outer strike point region ($r = 2.830$ m) and permits one to view the molecular emission spectra of CD in the wavelength region from 4240\AA to 4320\AA with a resolution of $\sim 0.2\text{\AA}$. Differences between the He concentration measured by the Penning gauge and divertor spectroscopy are due to the evolution of the composition of the wall recycling processes as the initially D-rich walls become He rich. These change-over experiments were conducted in a lower single null divertor configuration (see Ref. 1) and had the following plasma parameters: $I_p = 2.6\text{MA}$, $B_T = 2.1\text{T}$, and $P_{\text{ICRH}} \approx 5.0$ MW. Both the D to He change-over (53937 to 53941) and the He back to D change-over (shots: 54264 to 54268) used a fixed magnetic equilibrium and a reproducible ICRH power ramp to investigate the wall change-over processes. The same amount of He gas was injected in each of the change-over shots. During the experiments the JET divertor cryopump system was operational and has a pumping speed, $S = 100\text{m}^3\text{s}^{-1}$ for deuterium. The cryopump was not prepared with Ar frosting and therefore does not pump He.

3. HE CHANGE-OVER EXPERIMENTS

Figure 1 shows the measured He and deuterium partial pressures as a function of time after pure He gas is injected for 1.5 sec (51.5 – 53.0 s) in the first, mainly ohmic discharge of the He wall uptake experiment (53937), as given by the subdivertor Penning gauge. An ICRH power of 5.0MW was applied from 17.5s to 17.5s. Before these discharges only D has been exposed to the tokamak walls. Since only He is injected the small value of deuterium pressure is due to the deuterium evolving from the graphite walls of JET. The He pressure decreases throughout the discharge (53937) due to wall pumping of He, as well as the neutral beam box pumping system. Initially the wall is saturated with D and recycled particles of this species will persist for a number of discharges. The same conditions and He gas puff program of discharge 53937 is repeated for shots 53938 - 53941. The He concentration as measured by the Penning gauge for these 5 shots is shown Fig 2(a). In the first shot, 53937, the He concentration reaches a value of $\sim 85\%$, which is consistent with other He concentration measurements in both the core and edge plasma regions. During the period when ICRH heating is applied (17.5s to 27.5s), the He concentration drops to 50 - 70 % due to deuterium evolving from the graphite walls. During the ICRH heating period the He concentration rises with each successive discharge, due to the depletion of D trapped in the graphite wall. In Discharge 53941 no ICRH heating was applied.

After the first six He fuelled change-over discharges, only He plasma operation was performed on JET (for ~ 330 discharges). Following this investigation of pure He plasma operation, the situation is reversed and the change-over from an initially saturated He wall is investigated when only D2 plasma fuelling is used (54264 - 54268). Figure 2(b) shows the He concentration of this change-

over from He back to D operation. As shown in Fig. 2(b) the He concentration remains high (~80%) in the first D fuelled discharge (54264) and the He concentration still remains at ~10% after 14 discharges (54278). This indicates that the plasma fuelling efficiency is quite high for He and quite low for D. Figure 3 shows the He concentration for the entire He campaign indicating the very rapid change-over to He operation (>85% He) after 1-2 discharges. During the bulk of the pure He campaign on JET (53942 - 54262) the He concentration was ~95% and in the final phase (54264 - 54278) for the conversion back to D operation, the He concentration was still ~10% after 14 deuterium only fuelled discharges.

4. GLOBAL PARTICLE BALANCE BETWEEN DISCHARGES

The global particle balance gives insight into the exchanges of He particles between the wall and the plasma leading to a better understanding of the evolution of the wall particle inventory. In JET the particle balance equation [5] is

$$\int_0^t Q_{\text{gas}} dt + \int_0^t Q_{\text{NBI}} dt = \langle n_e \rangle V_p + \int_0^t P_{\text{ves}} S_{\text{ves}} dt + \int_0^t P_{\text{div}}^{\text{cryo}} S_{\text{div}}^{\text{cryo}} dt + N_{\text{wall}} \quad (1)$$

where Q_{gas} and Q_{NBI} are the particle injection rates associated respectively with gas puffing and neutral beam injection (zero for these cases), $\langle n_e \rangle$ is the volume averaged plasma density, V_p the gas Q_{dt} plasma volume, P_{ves} the neutral pressure in the vessel, S_{ves} the global pumping speed of the vessel (including vessel turbo-pumps and neutral beam boxes), P_{div} the neutral pressure at the divertor cryo-pumps, S_{div} the pumping speed of the divertor cryopumps and N_{wall} the amount of He particles trapped in the wall since $t = 0$. The only quantity not accessible to direct measurement is N_{wall} , which provides a method of estimating the number of particles directly trapped or released by the wall.

Figure 4 illustrates the He particle balance for shot 53937 using equation (1). For the time 51.5 to 57.5s, the He wall retention is found to be $\sim 1.5 \times 10^{21}$ He particles; whereas with the 5MW of ICRH power, He particles are actually lost from the wall due to wall heating and energetic particles striking the wall. From this initial period (11.5 to 17.5s) in 53937 and utilizing the area of the divertor strike zones (determined by divertor heat flux measurements) the He retention by graphite is $\sim 2.2 \times 10^{21}$ He/m². This agrees well with previous measurements[6], which found $(1-5) \times 10^{21}$ He/m² for graphite walls. Figure 5 shows the number of He particles in the wall, N_{wall} , as deduced from Eq. (1) for each of the He change-over discharges (53937-53944). Initially during the ohmic phase the wall retains He until it begins to saturate and by shot 53944 little He is retained by the wall. Similarly, in shot 53937 when ICRH heating is applied, He is liberated from the wall (negative wall loading) but in successive discharges the wall begins to fill more deeply with He and little or no He is liberated in shot 53944. The effect of ICRH heating on the ratio was reduced to negligible levels after 8-9 discharges. Throughout the He campaign the He concentration was typically ~ 95% (see Fig. 3).

5. CD/CH RESULTS

Helium plasmas also provide an opportunity to investigate a case where chemical sputtering of the graphite walls is markedly reduced. Spectroscopic measurements of the CD molecular band intensities, which covers the Q branch region of the $A^2\Delta - X^2\Pi$ transition, have been made near the divertor strike point. Figure 6(a) shows the CD molecular band intensity for the D to He change-over discharges (53937 - 53939) and Fig. 6(b) shows the CD band intensity for the He back to D change-over experiments (54264-54268). As shown in Fig. 6(a) the CD band is observed to nearly disappear during the first He discharge. This clearly demonstrates that D chemistry is stopped once He becomes the working gas. Figure 6(b) illustrates the reappearance of the CD band once D is again used for plasma fuelling in the He to D change-over experiments (54264-54268). In each successive shot shown in Fig. 6(b) the CD band intensity increases as the graphite wall is becoming more saturated with D.

CONCLUSIONS

He change-over experiments on JET provide a unique opportunity to study the deuterium to Helium wall exchange processes in a large tokamak with graphite walls. In the first He discharge of the He change-over experiments, a He concentration of $\sim 85\%$ was achieved, even with a deuterium saturated wall. It is also observed that most of the D in the near surface wall reservoir is removed by the He bombardment within a shot. Utilizing a global He particle balance, an estimate for the He wall retention is found to be $\sim 2.2 \times 10^{21}$ He/m², which is in good agreement with other estimates of He retention by graphite. Helium plasmas also provide an opportunity to investigate a case where chemical sputtering of the graphite walls is markedly reduced. Spectroscopic measurements of the CD molecular band clearly shows that the CD molecular band disappears during the first He discharge, demonstrating that chemical sputtering in D plasmas contributes strongly to the carbon production in the divertor.

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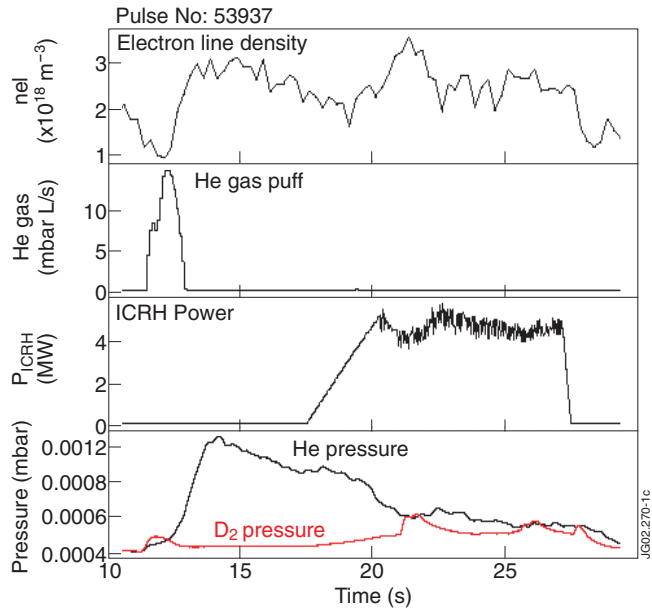


Figure 1: Typical plasma discharge (53937) for the D to He change-over experiments, where 100% He gas is injected into JET, whose graphite walls are saturated with deuterium.

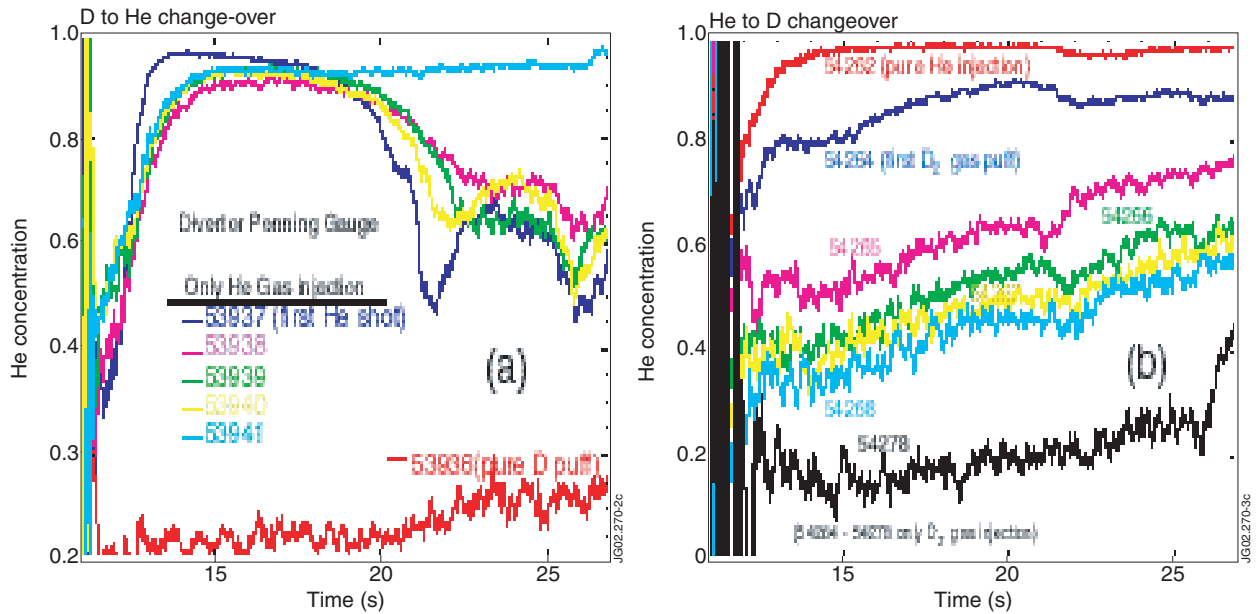


Figure 2: Penning gauge measurements of the He concentration in the divertor of JET during the (a) D to He change-over experiments where only He gas is injected into JET with an initially D saturated wall. (b) He to D change-over experiments where only D gas is injected into JET with an initially He saturated wall.

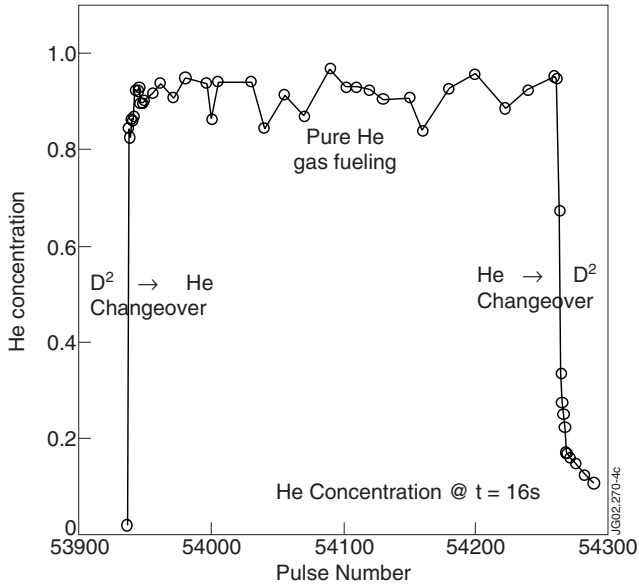


Figure 3: He concentration during the JET Helium campaign (~330 discharges) with initial change-over experiments from D to He (53937 - 53941) followed by the change-over back to D operation in shots 54264 - 54268.

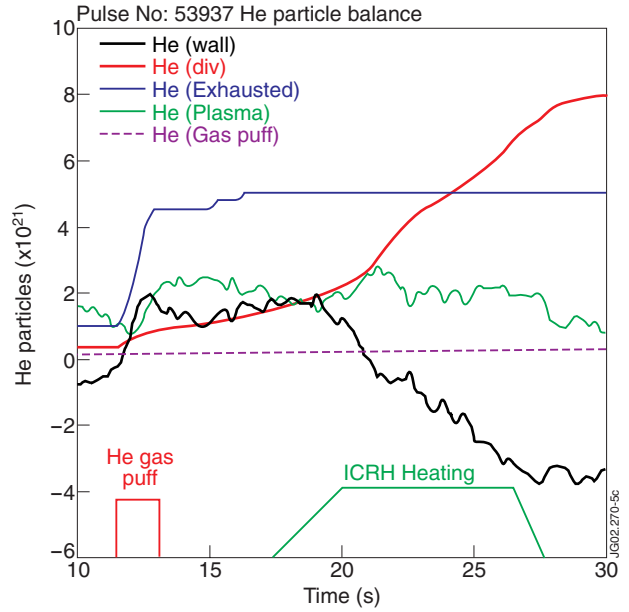


Figure 4: He particle balance for the first He change-over discharge (53937), where 100% He gas is injected into JET, whose graphite walls are saturated with deuterium.

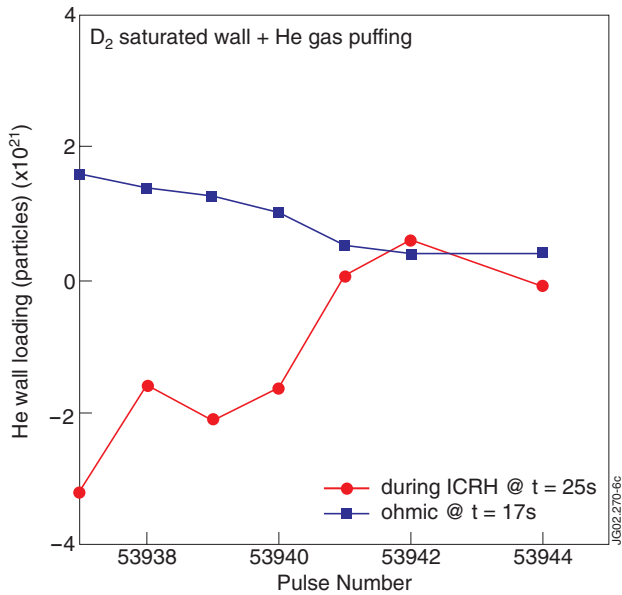


Figure 5: He particles in the walls of JET determined from the particle balance Eq. 1 during the D to He wall change-over experiment, where 100% He gas is injected into JET, whose graphite walls are saturated with deuterium.

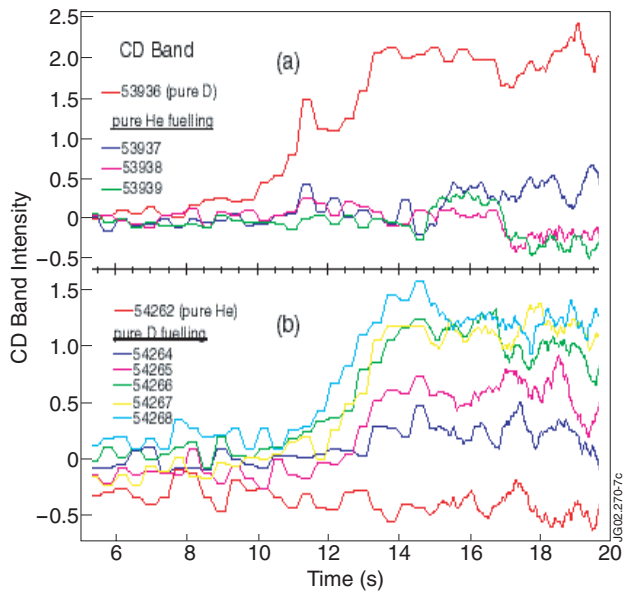


Figure 6: The CD molecular band versus time during the (a) D to He wall change-over experiment (53937 - 53939) and (b) He to D wall change-over experiment (54264 - 54268).