Impact of pellets on SOL-pedestal coupling in JET-ILW

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Introduction It is widely accepted that the SOL conditions can have a strong impact on the height (and structure) of the edge transport barrier. Gas dosing has been identified as one of the main contributors to the pedestal confinement reduction observed after the introduction of the ITER-like Wall on JET (JET-ILW) [1]. Linked to this, an inverse correlation was found between the pedestal top pressure ($p_{e,ped}$) and the relative radial displacement between the density (n_e) and temperature (T_e) pedestals ('relative shift') [6, 7]. More recently, the ratio of separatrix density over pedestal top density ($n_{e,sep}/n_{e,ped}$) [2] (which is closely related to the relative shift) has been identified as a more appropriate parameter to understand the pedestal reduction at JET [3]. In turn, $n_{e,sep}$ depends on the electron temperature at the outer divertor target ($T_{e,OT}$) via the 2-point-model (2PM) scaling, as recently also experimentally demonstrated in [4]. Substituting gas puffing by pellets effectively shifts the radial particle source from the plasma edge to inside the H-mode transport barrier. The main aim of the present work is to understand how this change of source localisation impacts the SOL and the SOL-pedestal coupling.

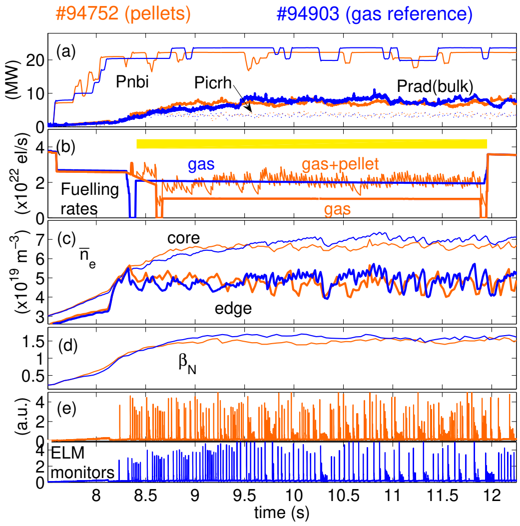

Figure 1: *Selected time traces for a pair of 3MA discharges in which approximately half of the gas fuelling was replaced by pacing pellets at fixed* Γ_{tot}.

Experimental setup All plasmas used here are low triangularity lower single null type-I ELMy H-modes with Deuterium as main species (also for the pellets). The discharges were run under attached divertor conditions with good pumping and moderate to high levels of recycling ($T_{e,OT}$ typically in range 10-25eV). Matched datasets were produced comparing large ('fuelling') pellets, small ('pacing') pellets, main chamber(MC) gas puffing and divertor gas puffing. For the first three, the total fuelling rate $\Gamma_{tot} = \Gamma_{gas} + \Gamma_{pel}$ was kept fixed, as for the exam-

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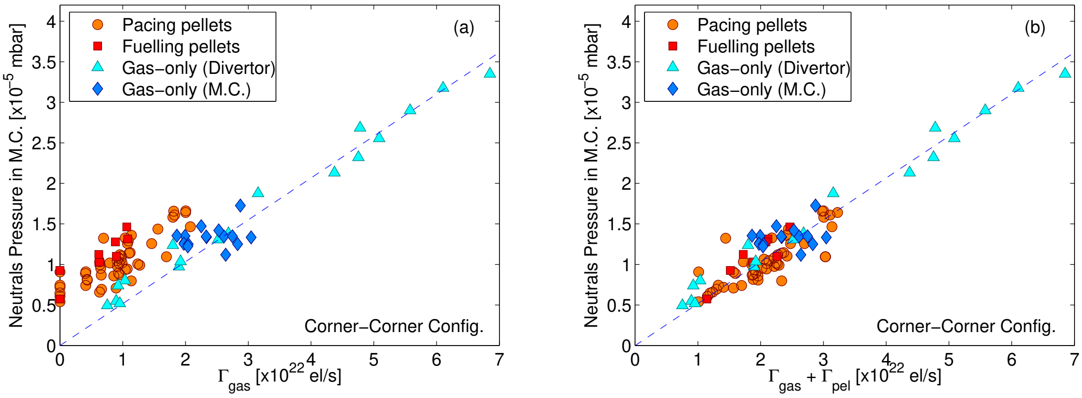

Figure 2: *Flat-top averaged neutrals pressure in main chamber for a wide database of discharges plotted (a) against the gas fuelling rate, and (b) against the total fueling rate (gas + pellets).*

ple shown in fig. 1. For divertor puffing, Γ_{tot} was not the reference quantity used because of its significantly lower fuelling efficiency at JET compared to MC puffing [5]. Instead, for the divertor gas fuelled discharges the gas rate was adjusted such as to match the ELM frequency (f_{ELM}) of their MC gas counterpart.

Impact on SOL Fig. 2 shows the neutrals pressure (p_0) measured by one of the main torus Penning gauges for a wide set of discharges with different I_p, B_t, heating and fuelling levels but retaining similar divertor geometry. Fig. 2a plots the data when considering only the gas fuelling contribution. While for the gas references p_0 is directly proportional to Γ_{gas}, both for MC and divertor puffing, the pellet cases systematically deviate from this trend. However, when the pellet fuelling contribution is also included (fig. 2b), the pellet pulses are well aligned with the gas discharges. The observation that pellets are contributing as much as gas puffing to p_0 strongly suggests that the neutrals content in the SOL is dominated by recycling.

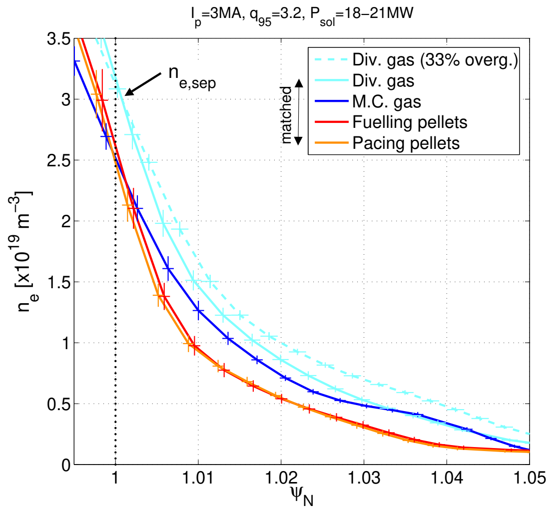

Figure 3: *Pre-ELM averaged upstream electron density profiles, measured by the Li-beam diagnostic.*

Fig. 3 shows the pre-ELM averaged n_e profiles in the main chamber SOL for a set of four matched 3MA discharges (solid lines). The plot also includes a moderately overgased (hence non-matched) fifth case (dashed), to bring the magnitude of variations among the four matched cases into perspective. In the pellet discharges a lower n_e in the SOL is measured than in the two gas-only counterparts. In the MC gas case the n_e profiles are flatter, while in the divertor gas case the n_e profile is primarily shifted outwards. It can also be seen in fig. 3 that the separatrix density remained essentially unaffected by the substitution of MC gas by pellets at fixed Γ_{tot}. On the other hand, the divertor gas puffing case has a 10-20% elevated $n_{e,sep}$, mainly as a result of the outwards shift.

Previous work [4] based on gas puffed discharges at JET showed that the $n_{e,sep}$ dependence on

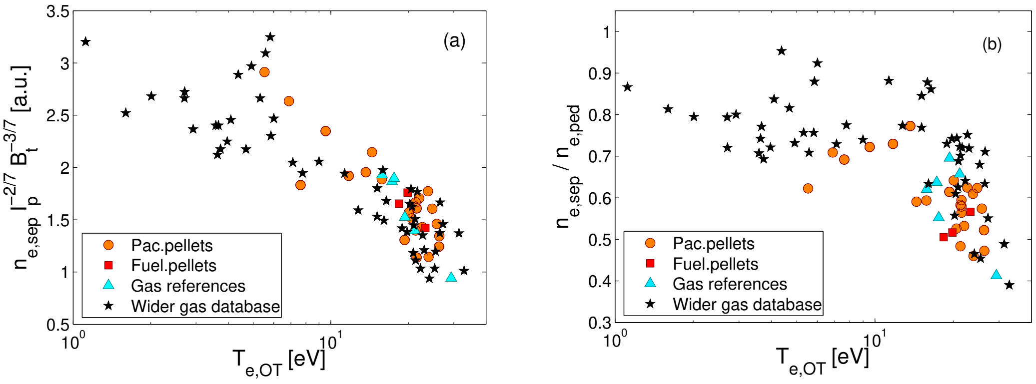

Figure 4: Pellet-gas database (coloured symbols) superimposed to a 'wider gas database' (black stars) that was first published in [4]. (a) $n_{e,sep}$ dependence on $T_{e,OT}$ (scaled with 2PM-based scaling factors to account for variations in I_p and B_t); (b) $n_{e,sep}/n_{e,ped}$ vs $T_{e,OT}$, for same dataset.

$T_{e,OT}$ followed the expected 2PM scaling, once volumetric loss factors are included. In that work, a comprehensive $T_{e,OT}$ database of gas puffed discharges was compiled (incl. different I_p, B_t, heating and gas levels, divertor geometry). In order to understand whether the physics governing formation of separatrix densities with pellets is different, this gas database was extended with a set of pellet discharges for which $T_{e,OT}$ information was available. $T_{e,OT}$ was obtained with Balmer photo-recombination continuum spectroscopy, following the same methodology as in [4]. The outcome of this comparison is shown in fig. 4, both for $n_{e,sep}$ (subfig. a) and the separatrix-pedestal top density ratio ($n_{e,sep}/n_{e,ped}$, subfig. b). It can be seen that the pellet pulses are effectively embedded in the wider gas dataset, which implies that the 2PM-based link between $n_{e,sep}$ and $T_{e,OT}$ also holds with pellets. The fact that the use of pellets does not break the separatrix fuelling trends strongly indicates that recycling in divertor and main chamber are the main drivers for fuelling separatrix, and the pedestal.

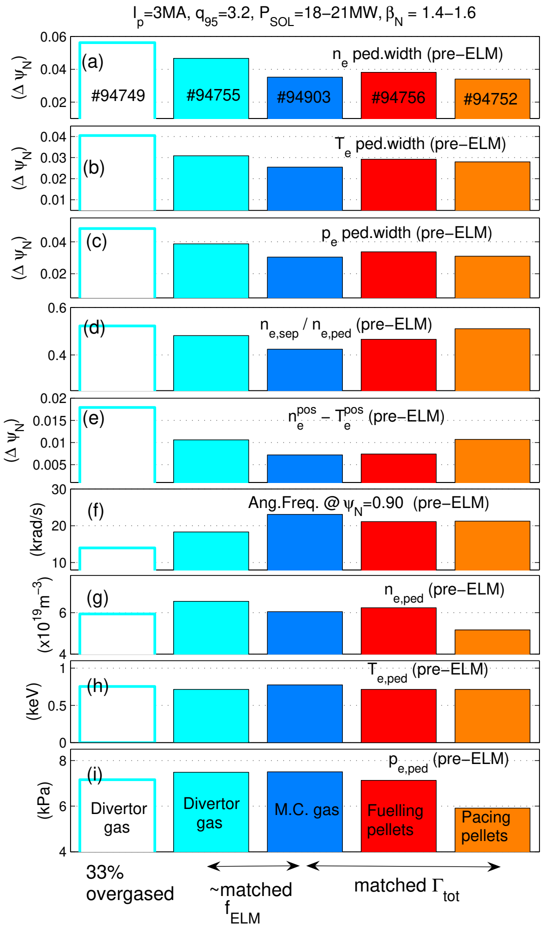

Figure 5: *Key pedestal indicators for the set of discharges of fig. 3: (a-c) Width* (ψ_N) *of* n_e, T_e *and* p_e*; (d)* $n_{e,sep}/n_{e,ped}$*; (e)* n_e *-* T_e *relative shift* ($\Delta\psi_N$)*; (f) tor. rotation near pedestal top* ($\psi_N = 0.90$) *- from CXRS; (g-i)* n_e,T_e *and* p_e *height. All quantities (except f) derived from tanh-fits to HRTS pre-ELM data.*

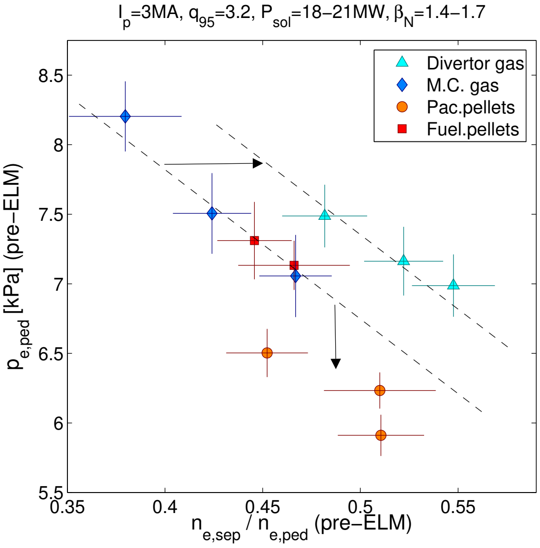

Figure 6: *Pedestal electron pressure height plotted against $n_{e,sep}/n_{e,ped}$ for a set of 3MA discharges with similar heating power but varying fuelling levels.*

Impact on pedestal-SOL coupling Fig. 5 shows a survey of key pedestal structure quantities for the same five discharges previously used in fig. 3. The main message that emerges from these measurements is that the pedestal structure in the first four cases (counting from left to right) is consistent with previous pedestal studies: The higher fuelling rate of the 'overgased' and 'divertor gas' cases leads to higher neutral pressure (fig. 2); this in turn drives their relative shift and $n_{e,sep}/n_{e,ped}$. These also lead an increase in the pedestal width (cf. expression 3 and figures 12 and 16 in [3]). Instead, the rightmost case (pacing pellets) does not fit into this logic, as both $n_{e,sep}/n_{e,ped}$ and the relative shift are elevated compared to MC gas and fuelling pellet cases despite having fixed neutrals content (Γ_{tot}). A closer inspection reveals that this anomaly has its origin in the markedly reduced pedestal density height (sub-fig. g) for the pacing pellets case (density 'pump out'), which in turn is caused by the pellet-driven ELM frequency increase ($f_{pel} > f_{ELM}$).
Do pellets impact the previously identified [2, 3] inverse correlation between the pedestal top pressure and $n_{e,sep}/n_{e,ped}$? Fig. 6 shows the corresponding data for an extended set of the previously used 3MA discharges for which the fuelling rate was varied further. It can be seen that the two fuelling pellet cases are well aligned with the MC gas cases, which indicates that the correlation still holds when gas dosing is replaced by pellets, as long as $f_{pel} < f_{ELM}$. The divertor gas dosing cases also show the expected negative correlation but they exhibit a finite offset towards higher $n_{e,sep}/n_{e,ped}$ whose origin is currently under investigation. Importantly, for the pacing pellet cases ($f_{pel} > f_{ELM}$) a stronger $p_{e,ped}$ reduction is observed than one would anticipate from their $n_{e,sep}/n_{e,ped}$ values. This finding is symptomatic of different physics involved in the pedestal pressure height reduction driven either by gas fuelling and pellet ELM pacing, which is in line with current physics models (SOL-pedestal interaction processes in the case of gas, 3-D localised perturbations in the case of pellet ELM triggering [8]).

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