Convection and Impurity Retention in the JET MkI Pumped Divertor in L-mode

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Forced convection in the SOL (by fuelling from the top, pumping in the divertor) is added to the natural convection driven by recycling and leakage of neutrals from the divertor. Comparison with discharges with only natural convection (fuelled from the divertor, pump on) shows small changes, including the predicted reduction in particle flux at the divertor target. Impurity control was investigated using trace neon puffs (~100 ms). Only small differences between top and divertor fuelling are observed; the trends are discussed.

1. Introduction: Forced convection (~5% target flux) was added to natural convection in the SOL by fuelling at top while pumping in the divertor. L-mode discharges were chosen, comparing top and divertor fuelling with pump on. The experiment was carried out with steady deuterium fuelling (top or divertor) and 3.4 *MW* NBI for 10 seconds, with/without a diagnostic neon puff (~100 *ms*) after 4 *s* either into top or divertor. A study without pump was reported in [1].

With forced convection in the SOL, what is predicted? That depends on the amount of natural convection. For example at high density if the natural convection into the divertor is 10% of target flux, then adding 5% forced convection gives 15% convection **(x1.5 flow)**; at lower density the natural convection might be 25%, so adding 5% gives 30% **(x1.2 flow)**. These estimates assume modest leakage of recycled neutrals from the divertor, but the leakage is difficult to measure. Changes due to the addition of 5% with top fuelling will be more obvious if the leakage and natural convection are lower (*e.g.* as expected with the *JET MkII* divertor) and vice versa.

Increased thermal convection (with $n_e^{SOL} \approx$ constant) reduces conducted heat flux and temperature gradients along the SOL. One expects a negligible change in T_e^{SOL} but an increase in T_e^{Target}. This leads to a decrease in density, particle flux and D_α at the target. The combined effects are to increase the frictional force pushing impurities into the divertor. Also, with smaller $T_e^{SOL} - T_e^{Div}$, the thermal force will be lower. Impurity retention should improve.

2. Experimental Details: A series of discharges was made, varying the fuelling location and that of the neon puff over a range of densities. We report on three pairs of discharges:-

1. Top neon puff, medium density,
2. Top neon puff, high density,
3. Divertor neon puff, high density.

Each pair includes one discharge with deuterium fuelling into the top, one into the divertor. Thus one can unfold density effects from fuelling and neon puff locations. The other discharges in the series include an L-mode power scan and a density scan and will be reported elsewhere. The main features of the discharges are: 2*MA*, 2.4*T* with sweeping; high wall clearance (determined experimentally), with high flux expansion in the divertor; constant fuelling rate (~ 2.5 and 5×10^{21} *D atom* s^{-1}) for 10 seconds (t = 10 to 20 *s*), the rates set to obtain medium density (3.3×10^{19} m^{-3} *line-averaged*) with the divertor in the high recycling regime and also to obtain high density (4.2×10^{19} m^{-3}) at which the ion saturation current at the outer target was approaching rollover but the plasma was partially detached at the inner target [2,3]. Slightly more D_2 fuel was required when fuelling into the divertor (10%-20%) because there was more pumping, the effects of which are discussed in [4,5]. The fuelling rate was about 4.5% to 6.5% of the total electron flux to the divertor target, measured with the probes. L-mode was chosen ($P_{NBI} = 3.4$ *MW* from 10 to 20 *s*), *i.e.* about two-thirds the H-mode threshold, because a range of densities could be studied. At t=14 *s* the diagnostic puff carried just enough neon to give ~ 0.5 *MW* of additional radiation, a measurable but relatively small fraction of the total input power (~4 *MW*). Even so, it affected the approach to detachment. With neon puffed into the divertor, ~ 30% more was required to achieve the same effect on the total radiation.

3. The Observations: The D_α photon flux and the total ion flow to the divertor targets were smaller with top fuelling than with divertor fuelling, but the difference was never as much as 20%. This reduction, presented as a ratio in Table 1, is clearly demonstrated at medium density at both targets but at high density the effect is barely significant. There is no apparent variation of the edge electron temperature with the fuelling location. These effects are broadly in accordance with predictions. The smaller effect at high density may be related to the onset of detachment.

Table 1. Ratio of fluxes with top deuterium fuelling to fluxes with fuelling in the divertor, measured at medium density (high density in parentheses).

	Inner target	**Outer target**
D_α photon flux	**0.83 (0.92)**	**0.96 (1.04)**
Total ion flux	**0.94 (1.02)**	**0.92 (0.94)**

Neon spectral signals in the core plasma (*NeVII, X,* Ne^{10+}*(cxs)*) and in the divertor (*NeI, II*) are shown in *Figs. 1-3* along with changes in Z-effective and in radiation. Not all the neon reaches the core, especially at high density, when the neon content is lower and decays faster (~ 3 *s*); at medium density the decay is slower (~ 5 or 6 *s*) and larger neon content is found, even after correcting for neon input *(see Fig.2)*; this is consistent with the carbon data. In contrast to expectations, top fuelling did not give lower neon content in the core. The core content was higher with top fuelling at medium density and "improves" to being independent of fuelling location at high density. There is scope for a genuine improvement at very high density or with a more closed divertor, *e.g.* MkII or the Gas Box Divertor, but this has not been demonstrated. The fraction of neon reaching the core is substantially larger than the ~2% found by McCracken et al [6]. This will be discussed elsewhere but the divertor cannot contain the missing fraction, which must have been pumped or absorbed in the walls.

In the divertor, radiation *(see Fig.3)* is larger with top fuelling at high but not medium density. Divertor neon content with top fuelling is estimated to be about the same as with divertor fuelling, on the basis of the measured *NeI* at inner or outer targets. There is an effect on *NeII* inner ~ 10 *cm* above the target (but not at the outer). The effect is small ~10-20% and is only seen at high density. This is supported by observations with the divertor bolometers.

4. Discussion: Why is there so little effect due to forced convection? If the SOL convection had increased by between 20% and 50% with top fuelling we would expect to have seen more evidence of the change. Why not? *(1)* Maybe there is more natural convection than expected, because neutrals escape through surfaces which should retain them in the divertor? *e.g.* if backflow and natural convection lie between 30% and 60% then a 5% perturbation would be hard to detect. Our result is consistent with this. The absolute values are not, but the discrepancies are ~10%. *(2)* Alternatively perhaps the convective flow pushes some but not all impurities into the divertor, *e.g.* sufficient to increase the radiation in the divertor but not to reduce the core content significantly. Alternative contributory factors are (a) that some fuel may be lost to the wall near the fuelling point at the top so there is less forced convection than expected - an experiment during the tritium phase of JET might help clarify this; (b) the thermal force is more important than expected; (c) there is backflow by either flow reversal or turbulence.

5 Comparison with Trends from EDG2D for MkI: The experimental results are recent and modelling of the discharges has just started. Comparison with simulations is only possible via trends in existing series of simulations [7]. In comparing one with only natural convection (no pump), the other with a fully modelled pump, there is an obvious difference in the two results, which are for nitrogen at a somewhat higher power ($10MW$) than our experiment. Although with the forced convection associated with pumping there is a reduction in total impurity content, the reduction is not very large and the core content is likely to be very high. With top fuelling there is a reduction in Z-effective ($2 \rightarrow 1.5$) and in electron density at the outer target ($1.46 \rightarrow 1.30 \times 10^{20} m^{-3}$).

6 Conclusion and Outlook: Convection caused by top fuelling is noticeable, producing flux changes consistent with simple models and suggesting that the forced convection due to fuelling and pumping is perhaps smaller than expected by say a factor of two. The convection had only a small effect on impurity screening and retention in JET. With the JET MkII divertor we expect far smaller natural circulation and more pumping [7] so changes in convection will be more apparent. The present experiment will provide a useful benchmark for comparison. Modelling of these experimental results is continuing. Finally, the rather small effect of forced convection in this L-mode experiment in JET is in marked contrast to the result of Schaffer et al, using argon in DIII-D in ELMy H-modes [7]. Apart from the difference in confinement, Schaffer compared forced convection due to fuelling at the top, pumping in the divertor with a discharge without strong fuelling. The fuelling appreciably altered the SOL in DIII-D as it does in JET. The experiments are not directly comparable.

[1] P J Harbour et al, 21st EPS, Montpellier, 1994, 18B partII, p 747.
[2] A Loarte et al, 22nd EPS, Bournemouth, 1995
[3] R Monk et al, 22nd EPS, Bournemouth, 1995
[4] G Saibene et al, 22nd EPS, Bournemouth, 1995
[5] J Ehrenberg et al, 22nd EPS, Bournemouth, 1995
[6] G McCracken et al, 22nd EPS, Bournemouth, 1995
[7] A Taroni et al, 22nd EPS, Bournemouth, 1995
[8] M J Schaffer et al, GA report, GA-A21687, March 1995, to be published in Nuclear Fusion.

Acknowledgements We acknowledge the contributions of many colleagues, in particular Mr Markus Beringer for support in organising and analysing the data.

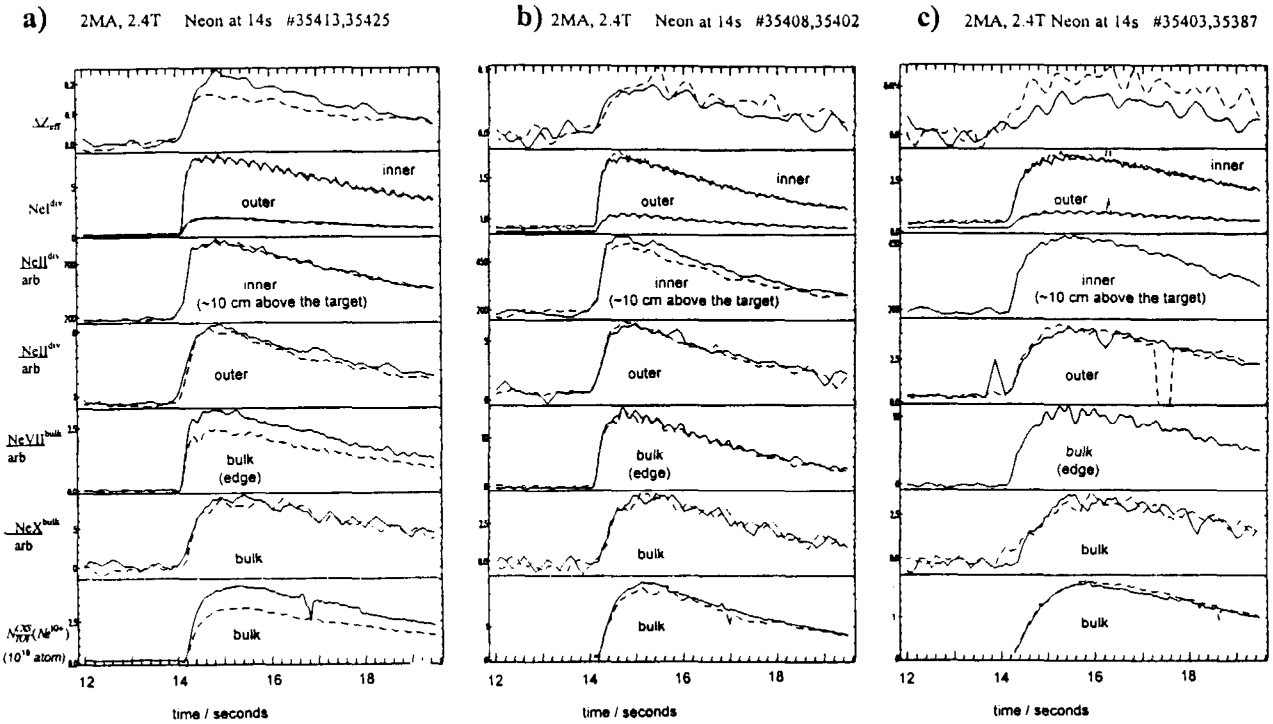
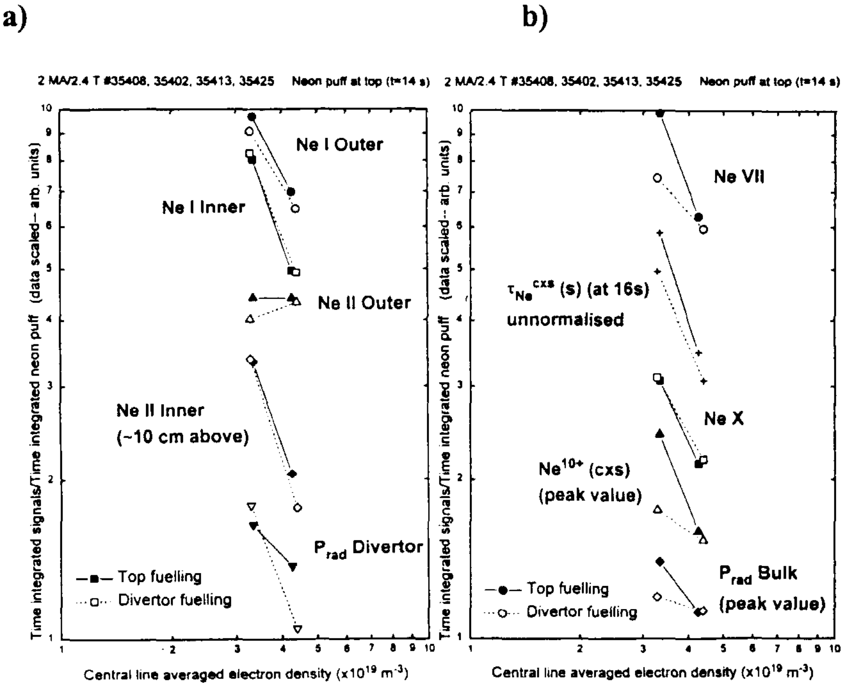


Figure 1 Spectroscopic results versus time. Three pairs of discharges are illustrated (see Section 2). a) and b) include a top neon puff (~100 ms) at 14 s, at: a) medium density (3.3x10^{19} m^{-3}); b) high density (4.2x10^{19} m^{-3}). c) shows results at high density (4.2x10^{19} m^{-3}) for a neon puff (~100 ms) into the divertor at 14 s. —— Top Fuelling; - - - - Divertor Fuelling. For each pair the amount of neon puffed was slightly different, with "pair b" receiving about 20% less than "pair a" and "pair c" about 20% more. Note that the slower rise in spectroscopic signals with divertor neon is in part due to a longer time constant of the gas feed pipes.



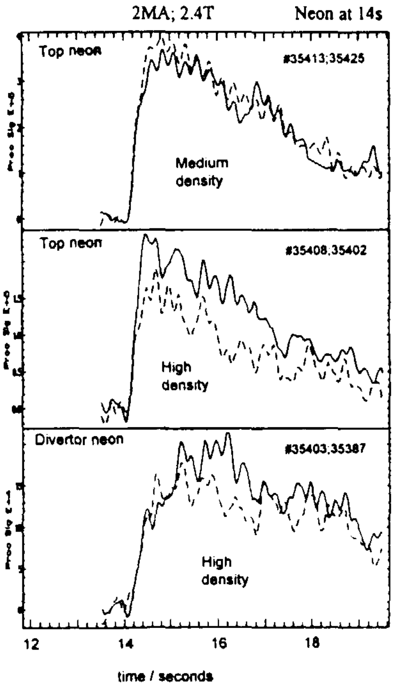


Figure 2 Spectroscopic results versus density. a,b) are for the same pairs of discharges as in Figure 1a,b). With only one exception the signals decrease with density, as does the retention time. —— Top Fuel; - - - - Divertor Fuel.

Figure 3 The increase in radiation in the divertor when neon is added, plotted versus time.