INVESTIGATION OF MOMENTUM DETACHMENT IN A STATIC GAS TARGET

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1. INTRODUCTION

A gas target, providing a pressure drop along field lines (momentum detachment), has been found to be a prerequisite for achieving acceptable divertor conditions in ITER [1]. Momentum transfer from ions to neutrals by elastic and cx-collisions (friction) has been identified as the basic mechanism to achieve this [2]. In steady-state, the friction force exerted onto the neutrals has to be balanced by either transverse losses of neutral momentum ($i-n$ induced transport or prompt losses, dynamic gas target [3]) or by a neutral pressure gradient (Static Gas Target, SGT). Transport or prompt losses dominate in a regime where $\lambda_{n-i} \geq \Delta$ (where λ_{n-i} is the neutral-ion mean free path and Δ the SOL width). If $\lambda_{n-i} << \Delta$, momentum losses are small and the plassma pressure gradient has to be balanced by a neutral pressure gradient.

Experimentally, detachment is usually approached by ramping up the density at otherwise fixed discharge parameters. In most devices detachment is a gradual process, which exhibits as a rollover of I^+_{sat}, followed by a gradual decrease. Simultaneously the D_α signal increases and the divertor pressure drops by about an order of magnitude at basically unchanged or moderately changing upstream conditions.

A decrease of I^+_{sat} (and divertor pressure) may be caused by a decrease of the power into the gas target, for instance as a consequence of an increase of radiation during the density ramp up. This trivial effect contributes in most discharges, but is insufficient to explain the observed huge drops of the ion saturation current and pressure. JET, in particular, has given clear evidence of a drop of I^+_{sat} even at constant net input pow

In this paper the potential of SGTs to provide a drop of the plasma pressure alo B and to reproduce the other characteristic phenomena of detachment, is investigated with a view to JET detached discharges.

2. MODEL DESCRIPTION

The analysis is performed using the time dependent SOL-One, 1-D scrape-off layer transport code [4], which is coupled to a fluid neutral gas model. SOL-One comprises the usual scrape-off layer fluid equations for the plasma (continuity equation, electron and ion temperature equations and the momentum equation along B) [5]. A slab model is used, but inclined field lines (with a constant field line pitch ψ) are taken into account. In the high collisionality limit the neutrals can, similarly to the plasma, be described by fluid equations for particle, energy and momentum conservation. Different from the plasma, the motion of neutrals is intrinsically two dimensional. Therefore, two independent momentum equations have to be solved. Collisions are assumed to be sufficiently frequent so that (i) $T_i \simeq T_0$ and (ii) transverse neutrals induced transport is negligible. Then a 1-D approximation (averaging over prescribed radial profiles) can

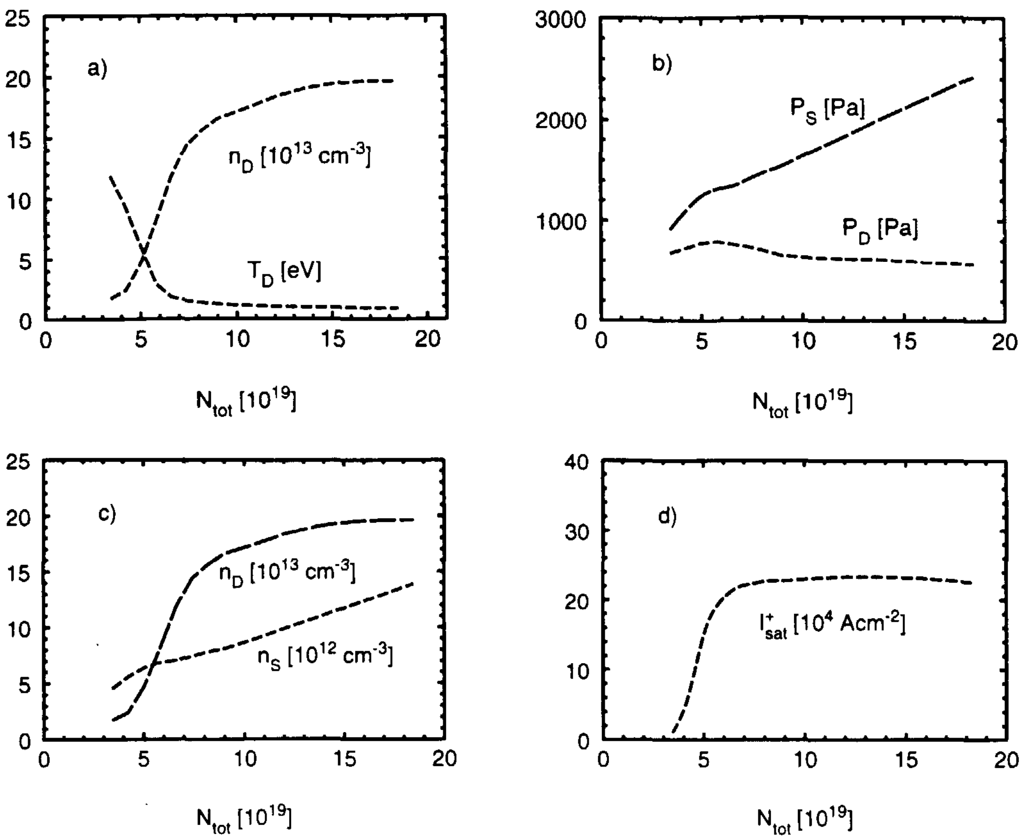

FIG. 1. *Various divertor and upstream parameters versus N_{tot}. Here n_D is the divertor density, n_S is the upstream separatrix density, $T_{e,D}$ is the electron divertor temperature, P_S and P_D are the upstream and divertor plasma pressures, respectively, and I^+_{sat} is the ion saturation current.*

be applied to the neutrals in complete analogy with the plasma, and ion and neutral energy transport can be described by a combined energy balance equation. A similar approach has been described in Ref. [6].

3. DESCRIPTION OF STUDY POINT

A discharge similar to JET shot 30829, which particularly clearly shows the drop of I^+_{sat} at constant net input power, is adopted as study point [7]. The main input parameters are: $P_{in} = 0.6\ MW$, $\sin\psi = 0.1$, L (total connection length) $= 2640\ cm$, L_X (plate to X-point distance) $= 240\ cm$. All profile decay lengths are kept fixed at a common value of 2 cm. We simulate a typical density ramp up scenario by performing a sequence of runs with successively increasing the particle content N_{tot} at otherwise constant input parameters.

4. SUMMARY OF RESULTS AND DISCUSSION

Results are summarized in Figs 1 a) - d). The spatial distribution of various quantities is given in Figs 2 a) - d) for an intermediate case ($N_{tot} = 15.3 \times 10^{16}$).

For divertor temperatures above $\approx 5\ eV$, $P_D/P_S \simeq 1/2$ holds as expected for a system where $i - n$ collisions do not play a role. With decreasing T_D, P_D/P_S indeed

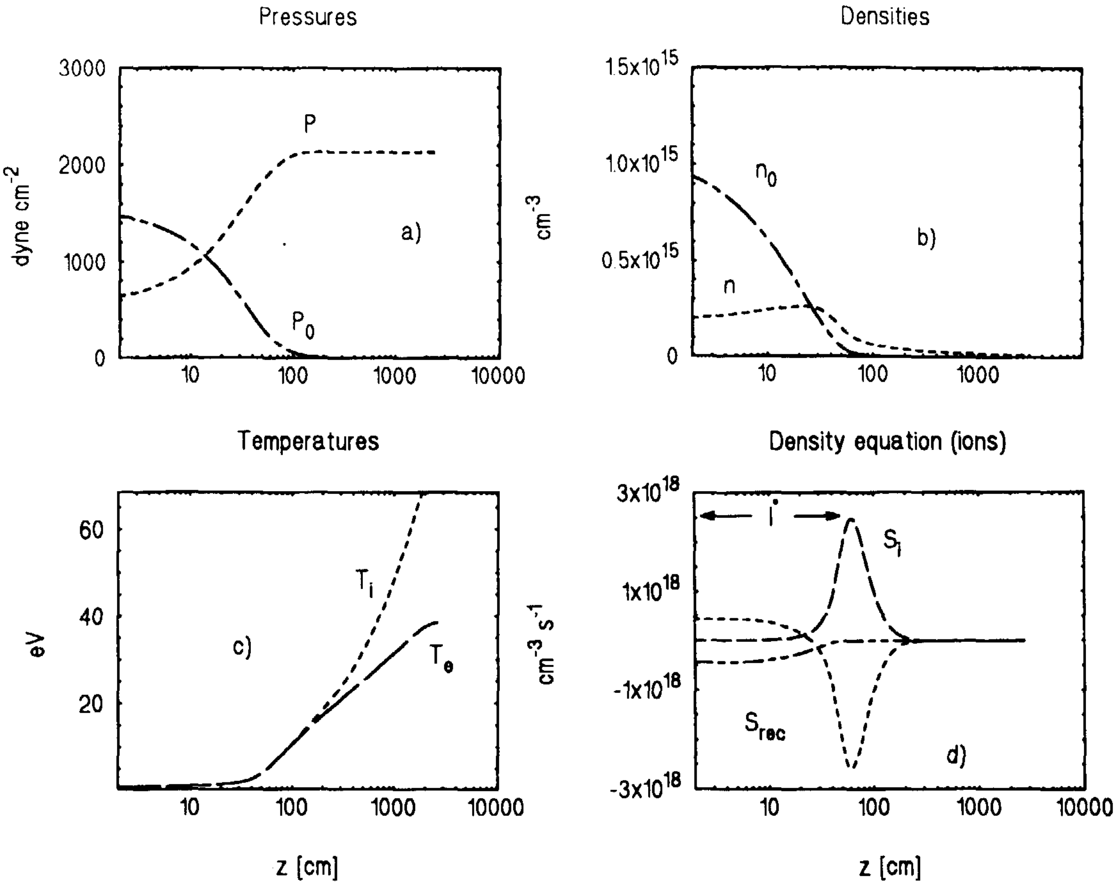

FIG. 2. *Shape of various quantities along B. The plate is at* $z = 0$. *Fig. d) shows the spatial variation of the right-hand side terms in the ion continuity equation. The ionization source term has a pronounced peak at the distance* ℓ^* *from the plate, which is identified with the gas target entrance.* $N_{tot} = 15.3 \times 10^{16}$ *in this case.*

drops, indicating an additional pressure drop along B. However, this is mainly due to an increase of P_S, while P_D drops only very little. Generally one concludes from Fig. 1 that all divertor quantities (n_D, $T_{e,D}$, I^+_{sat}) tend to saturate with increasing N_{tot}, while the upstream quantities (n_S, P_S) continuously increase. This indicates that the additional particles fed into the system mainly accumulate in the upstream region. Different from what is typically seen in experiments, I^+_{sat} does not drop with increasing N_{tot}.

It has been generally found difficult to describe the drop of I^+_{sat} (and the increase of D_α) by $i - n$ collisions alone. Recent studies of the dynamic gas target regime have reveiled that, with (radiative and three body) recombination included, both a drop of I^+_{sat} and an increase of D_α follow naturally. In the present study the same recombination model is used, but recombination is found to be insignificant, since the ion density stays at comparatively low values in the gas target region (see Fig. 2 d)). Recently, H_2 catalyzed recombination has been discussed as a potentially significant channel [$e + H_2(\nu) \rightarrow H^- + H$; $p + H^- \rightarrow H + H^*$ resulting in the overall reaction $p + e + H_2 \rightarrow 3H$] [8], which would increase with increasing neutral density. An adequate treatment of this mechanism is beyond the capability of the present model. However, tentative calculations, assuming that a given fraction of neutrals are vibrationally exited molecules ($n_{H_2(\nu)}/n_0 = 0.005$) leads to solutions which are in much better agreement with experimentally observed patterns and similar to the dynamic gas target results.

Despite of this, the SGT is hampered by intrinsic consistency problems which limit its applicability at least in typical present tokamak experiments. This regime, in order to prevail, requires two conditions to be fulfilled: (i) $\lambda_{n-i}/\Delta << 1$, i.e. that the neutrals are collisional in transverse direction with respect to $i-n$ collisions and (ii) $\frac{\Delta}{\ell^* \sin\psi} << 1$, to make transverse neutral induced transport negligible. For the data given in Fig. 1 one gets $\lambda_{n-i} \approx (\sigma_{i-n} n_D)^{-1} \approx 1\ cm$, indicating that condition (i) would be at least marginally fulfilled in JET ($\Delta \simeq 3\ cm$ in the present configuration). However, with $\ell \simeq 50\ cm$ and $\sin\psi \simeq 0.1$, condition (ii) is rather difficult to fulfill in JET and generally in configurations with moderate flux expansion. If, as in the case of advance recombination models, I^+_{sat} drops, the divertor densities drop to much lower values than those of Fig. 1, making also condition (i) questionable.

In Ref. [6] it has been shown (in agreement with our findings) that I^+_{sat}/P_S and P_D/P_S drop with decreasing T_D and it is claimed that this provides an explanation of observed detachment behaviour. However, we have found that, if N_{tot} is ramped up at constant power into the gas target, the situation prevailing in typical high density discharges, the reduction of I^+_{sat}/P_S and P_D/P_S is mainly due to an increase of P_S instead of a reduction of I^+_{sat} and P_D. Also, T_D is clamped and temperatures below a certain value cannot be accessed in this scenario.

5. CONCLUSION

The potential of a SGT to describe the characteristic evolution of SOL parameters when detachment is approached (rollover) has been studied with a view to JET parameters. Momentum detachment is found, but typical experimental observations, in particular the drop of I^+_{sat}, are not reproduced. Inclusion of H_2 catalyzed recombination might give better agreement. However, general conditions for the existence of a SGT are difficult to fulfill in typical tokamak experiments.

ACKNOWLEDGEMENT

One of the authors gratefully acknowledges discussions with S. I. Krasheninnikov.

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