THE EFFECTS OF WALL AND LIMITER MATERIAL PROPERTIES ON HYDROGEN RECYCLING IN JET

J Ehrenberg°, S A Cohen*, L de Kock, P J Harbour,
P D Morgan, M F Stamp and D D R Summers

JET Joint Undertaking, Abingdon, Oxon OX14 3EA, UK
° On attachment from Max-Planck-Institut für Plasmaphysik,
8046 Garching bei München, FRG
* Visiting scientist from Plasma Physics Laboratory,
Princeton University, Princeton NJ 08544, USA

I INTRODUCTION

The recycling of hydrogen at the limiters and walls of a fusion machine is important in controlling the particle and power balance of the plasma.

The problem may be subdivided into two parts: the transport of particles in the plasma and the transport of particles in the limiters and walls. In this paper we concentrate on the transport in the limiters and walls, treating plasma transport in a global way.

We present a numerical model which predicts, as a function of time during a simulated plasma discharge, the number of plasma particles and the particle fluxes to and from limiters and walls. We study with this model a JET discharge in which the plasma was moved from the outer limiter onto the inner wall and back to the limiter. We find good agreement between experiment and simulation.

II EXPERIMENTAL ASPECTS OF RECYCLING IN JET

JET limiter discharges are initiated with a hydrogen or deuterium gas prefill. A subsequent dosing raises the density. When the dosing valve is closed the density stays approximately constant /1/. The number of particles found in the plasma, compared to the number admitted into the machine (the fuelling efficiency) depends on the conditions of the limiters and walls. However, the walls and limiters soon reach a steady state in which the fuelling efficiency is below one.

In some JET discharges, the plasma is moved from the outer carbon limiter onto the inner carbon wall. Subsequently the plasma density drops. This pumping at the inner wall is not reduced after a series of similar discharges, excluding the saturable trapping of hydrogen implanted into carbon as a pumping mechanism. Also, we estimate that pumping due to deuterium/carbon codeposition /2,3/ contributes less than 30%, otherwise the required erosion rate of carbon would have to exceed that from known processes by a factor of three. When the plasma is moved back to the outer limiter, the density rises again. An example is shown in Fig. 1. This indicates that changes in the plasma position may be considered as changes in the balance between the particle fluxes out of the plasma and those out of walls and limiters.

III THE RECYCLING MODEL

The walls and limiters in a fusion machine are a reservoir for hydrogen atoms in the same way as the plasma is a reservoir for ions /4,5/. The neutral gas phase is unimportant as a reservoir because its confinement time for neutrals is of the order 10^{-3} s and thus much smaller than the particle confinement time τ_p in the plasma. Walls and limiters, in order to be an important reservoir, must have a particle confinement time τ_w similar to the plasma particle confinement time. The plasma is the source for energetic ions and neutrals which impact the walls. τ_w can be considered as the time these particles need to diffuse back to the surface and to desorb into the plasma. This effect is well-known for the case of hydrogen in metals and is called transient or dynamical retention /6/. However JET has carbon limiters, carbon inner walls and inconel vessel walls which are covered with a carbon layer (> 10 nm) /7/. In addition the carbon is saturated with deuterium, contaminated with metallic impurities and may have cracks at the surface. Little is known about dynamical retention in such materials. Nevertheless, we use the concept of hydrogen diffusion in solids and develop a model to calculate the number of plasma particles as well as particle fluxes from walls and limiters.

We assume that the change in the number of plasma particles (N_p):

$$\frac{dN_p}{dt} = - \frac{N_p}{\tau_p} + f \cdot \phi, \qquad (1)$$

where ϕ is the total flux of deuterium atoms from walls and limiters and f is a factor taking into account that part of this flux returns directly to the limiters and walls due to atomic processes, ionisation in the scrape-off layer, or due to the escape of neutrals. The magnitude of f has to be estimated.

Plasma losses, N_p/τ_p, are assumed to stream either to the outer-limiters or to the inner wall, depending on where the plasma resides. The flux $(1-f)\phi$, which is that part which does not fuel the plasma, is shared between the limiter, the inner wall, and the rest of the vessel wall. It is assumed that 50% of this flux goes to the surface where the plasma resides (limiter or inner wall) and 50% to the rest of the wall and the inner wall or limiter (i.e. depending on where the plasma is not). The latter 50% is assumed to be shared according to the ratio of the respective surface areas. The partition is somewhat arbitrary, however it simulates roughly the situation that the probability of creation of "daughter"-neutrals by charge exchange processes is largest near surfaces where recycling is large. Thus "daughter"-neutrals have a good chance to return to that surface where the initial neutrals have been born.

The particles which impinge onto surfaces are either reflected (with reflection coefficient, r) or penetrate into the material up to a depth d. r and d depend on the impact energy of particles, which is derived from Langmuir probe measurements in the plasma boundary of JET /8/. For simplicity we assume monoenergetic particles. The penetrating particles are the source for the diffusion in walls and limiters. The diffusion equation is solved numerically, using an assumed diffusion coefficient, a recombination coefficient, and appropriate boundary conditions. The diffusive losses as well as the reflected flux from all surfaces then fuel the plasma (see equ 1). From the dependence of the experimental fuelling efficiency on the number of particles admitted to the machine, it can be shown that the release of particles from JET limiters and walls is most likely determined by diffusion. Thus we have to know the diffusion coefficient only. We also have to know whether diffusion takes place within the entire wall thickness ($\leq 10^{-2}$ m) or only within a surface layer with a thickness L. Assuming a simple triangular concentration profile of diffusing particles in limiters and walls (peaked at the range d and zero at either surface of the layer L) it can be shown that the wall confinement time τ_W is approximately:

$$\tau_W \sim \frac{d \cdot L}{D} \text{ if } L > d \text{ and } L << (t_{max} \cdot D)^{1/2} \qquad (2)$$

where t_{max} is the duration of particle bombardment. If $L \geq (t_{max} \cdot D)^{1/2}$, τ_W is larger than in (2) and depends on time. In this case (or when $d > L$) it can be shown that the plasma is still pumped by the walls, however, the number of particles cannot increase during a discharge as is shown to occur in Fig. 1. Good agreement between experiment and calculation was found by taking L to be around 20 nm. This suggests that the material structure of wall and limiter surfaces prevents the diffusion of a significant fraction of deuterium into the bulk material.

IV RESULTS

For the calculation presented in Fig. 2 we took a reflection coefficient, r, of 0.3 and a particle range, d, in walls/limiters of 5 nm corresponding to an impact energy of about 100 eV for deuterium on carbon. According to previous investigations /1/ τ_p was taken to be proportional to $1/N_p$. To simulate the higher temperature at the limiter (> 700°C) compared to the walls (300°C) and the different materials (carbon, carbonized inconel), we assumed the diffusion coefficient D to be different on these surfaces. D and the factor f (see Fig. 2) were varied until satisfactory agreement with the experiment was achieved. The discharge scenario simulated in Fig. 2 is as follows: an external gas source with 10^{21} particles/s for the first 4 s, fills the plasma while it rests at the limiter. The total particle input is the same as in the experiment of fig. 1. At 6 s the plasma interaction is shifted from the limiter to the inner wall. At 10 s this is reversed. To simulate the detached plasma phase at 6 s and 10 s the plasma particle confinement at these times was enhanced for 0.2 s by a factor of 2. Good agreement between calculation and experiment was achieved with $D = 2.10^{-11}$ cm^2/s at the limiter, $D = 1.10^{-11}$ cm^2/s at the inner wall, and $D = 1.10^{-12}$ cm^2/s at the rest of the wall. The set of values for d, L, D and f is not unique. The limiter flux, deduced from the data in Fig. 1 agrees within a factor of 2 with that in Fig. 2. However the measured inner wall D_α-signals show toroidal variations, probably caused by non-uniformities in the surface of the inner wall, making a quantitative comparison difficult.

V CONCLUSION

A model has been developed to describe the complementary processes of pumping and fuelling of plasma by diffusion of deuterium in limiters and walls. Also account is taken of non-fuelling processes which increase particle fluxes to walls/limiters and subsequently the particle inventory therein. Comparison with experimental results shows good quantitative agreement. The model indicates the importance of plasma and wall properties for the balance of particle fluxes.

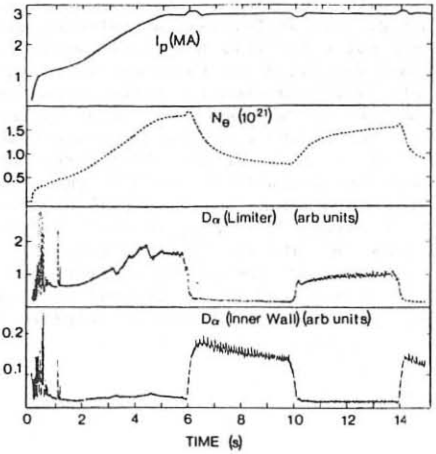
VI REFERENCES

/1/ P Morgan et al, Proceedings 12th Europ Conf Contr Fus Plasma Phys, Budapest, 2-6 September 1985, Vol II, 535.
/2/ R Behrisch et al, Journal of Nucl Mat, 145+147 (1987) 723.
/3/ H Bersaker et al, Journal of Nucl Mat, 145+147 (1987) 727.
/4/ G M McCracken and P E Stott, Nuclear Fusion, Vol 19, No 7 (1979) 889.
/5/ T Jones et al, this conference.
/6/ F Waelbroek et al, Journal of Nucl Mat, 111+112, (1982) 185.
/7/ P Coad et al, Proceedings 12th Europ Conf Fus Plasma Phys, Budapest, 2-6 Sept 1985, Vol II, 571.
/8/ T Tagle et al, this conference.

FIGURES

Fig. 1 Plasma current I_p, total number of electrons N_e, and D_α signals from limiters and inner wall of a JET discharge which was moved onto the inner wall at t=6s and removed back to the limiter at 10 s and again moved to the inner wall at 14 s. To compare N_e with N_p of fig. 2, N_e has to be reduced by approximately 20% due to Z_{eff} = 2, assuming carbon as the only impurity.

Fig. 2 Calculated number of plasma particles N_p and particle fluxes from limiter, Γ_L, and inner wall, Γ_{IW} for a discharge with a similar total particle inventory as in Fig. 1.



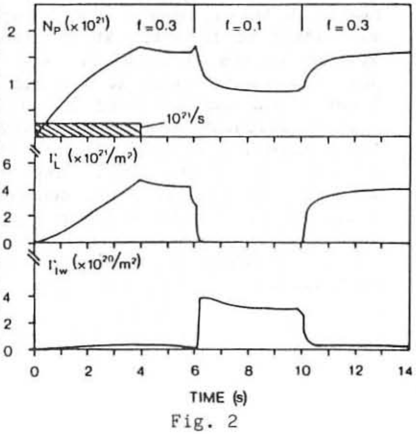


Fig. 1

Fig. 2