PARTICLE BALANCE STUDIES IN JET

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1. Introduction

Global particle balance gives insight into the exchanges of particles between the wall and the plasma leading to a better understanding of the plasma density behaviour. In addition, it gives access to the evolution of the wall particle inventory, which is crucial for the tritium experiments as demonstrated in the D-T campaign on JET in 1997-1998 [1].

In JET, the particle balance equation can be written

$$\int_0^t Q_{gas}dt+\int_0^t Q_{NBI}dt+\int_0^t Q_{pellet}dt=\langle n_e\rangle V_p+\int_0^t P_{ves}S_{ves}dt+\int_0^t P_{div}S_{div}dt+N_{Wall} \qquad (1)$$

where Q_{gas}, Q_{NBI} and Q_{pellet} are the particle injection rates associated respectively with gas puffing, neutral beam injection and pellet injection, $<n_e>$ is the volume averaged plasma density, V_p the 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) related to P_{ves}, P_{div} the neutral pressure at the divertor cryo-pumps, S_{div} the pumping speed of the divertor cryo-pumps related to P_{div} and N_{wall} the amount of particle trapped in the wall since $t = 0$. The equation is verified at any time during and between the pulses. In principle, the only quantity not accessible to direct measurement is N_{wall}. The knowledge of the other terms can give, as a function of time, an estimation of the exchange of particles between the wall and the plasma. In the "classical" particle analysis, the global balance is performed over the pulse duration only allowing dynamic wall retention to be detailed. In this paper, long-term retention is also discussed.

2. Determination of the pumping speeds

Due to the presence of the divertor cryo-pumps [2] and the neutral beam box cryo-pumps, the pumping speeds play a major part in the particle balance and their determination is one of the key factor of the accuracy of the balance. Daily "dry runs" have been used to estimate the pumping speeds S^P, related to a neutral pressure measurement P, according to the following expression

$$S^P=\frac{\int Q_{gas}dt}{\int Pdt} \qquad (2)$$

As the product pressure-pumping speed is the relevant value in the particle balance, this integral method avoids the pressure gauge calibration problem and gives the effective pumping speed (not absolute) needed to calculate the exhaust. The obtained values are given on table I.

	Vessel turbo-pumps	NBI cryo-pump/box	Divertor cryo-pump
S^{Pves} (vessel mid-plane TT03)	9 m^3/s	40 m^3/s	125 m^3/s
S^{Pdiv} (sub-divertor KT5P)	-	-	250 m^3/s

Table I : effective pumping speeds for deuterium (assuming T_{gas}=593°K).

However, the comparison of the amount of gas released by the divertor cryo-pumps during regeneration and the amount of gas calculated by the time-integrated $P_{div}S_{div}$ over the same period of operation, implies that the pumping speed value found during dry run is not valid during X-point plasma. The location of the pressure gauge with respect to the cryo-pumps and the different pressure distribution in the sub-divertor during X-point plasma (due to leakage from the sub-divertor to the main chamber ~100 m^3/s) can explain that fact [3]. As the network of conductance in the sub-divertor is not well known (MkII-GB), the effective pumping speed during X-point plasma has to be worked out from cryo-pump regenerations. A value of 110 m^3/s has been found (related to KT5P to be compared to 250 m^3/s in dry-run, table I).

3. Particle balance for typical discharges

Using the previously estimated pumping speeds according to the situation, the particle balance has been performed extensively over a wide range of discharges. Figure 1 shows the results for two typical JET discharges.

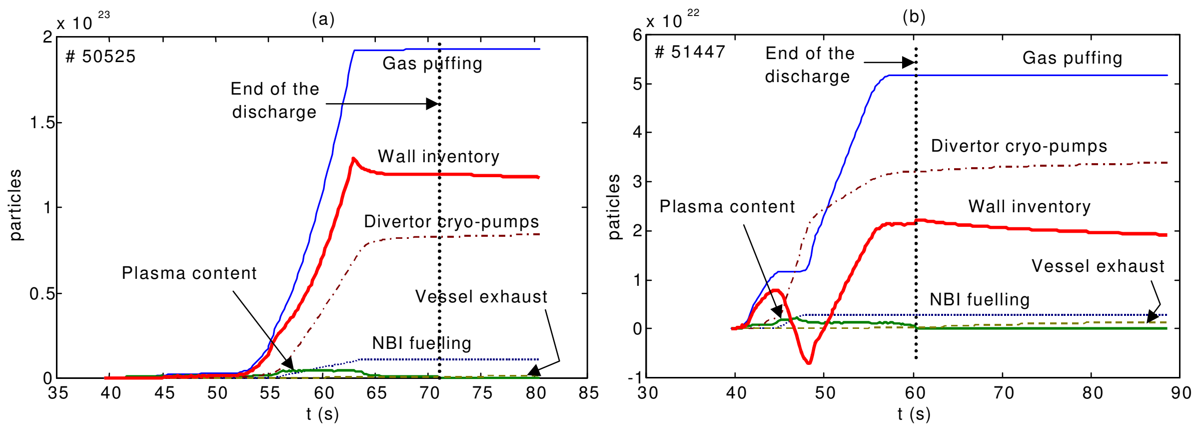

Figure 1 : Particle balance for two typical JET discharges : (a) ELMy H-mode (2.8MA/3.0T); (b) ITB discharge (2.3MA/2.6T).

In the ELMY H-mode (Fig 1a), after the X-point formation, a strong injection of deuterium (2 10^{23} particles ~ 421 $Pa.m^3$) is necessary to rise the plasma density to the requested level (up to ~0.6 $n_{Greenwald}$). The gas injection continuously loads the wall and the divertor cryo-pumps while the plasma content remains small (4-5 $Pa.m^3$) in comparison with the injection. At the end of the discharge, nearly 60% of the injected particles are trapped in the wall.

In the optimised shear discharge (Fig 1b), different phases can be observed. In the first phase (40-44 s), a strong gas injection slowly builds up the plasma density while strongly increasing the wall inventory. At t = 44.5 s, the gas injection is stopped and the neutral beams start to fire. The plasma density rises immediately and the wall begins to release particles. At t = 48 s, the beams are stopped, the gas injection resumes and the wall is filling up again until the end of the gas puffing. At the end of the discharge 35% of the injected particles is dynamically retained in the wall (39.5 Pa.m^3). In both discharges the plasma content is nearly negligible as compared to the global balance and the wall retention strongly depends on the rate of injection and on the total amount of gas puffed in the vessel during the plasma.

In the average, 50% of the injected particles is dynamically retained in the walls at the end of the discharge and then slowly released between the pulses while the other 50% is pumped during the discharge by the divertor cryo-pumps.

4. Particle balance for long-term analysis

The same calculation has been extended between the pulses and during the night to access the long-term gas retention. Figure 2 displays the vessel pressure measurement during one typical week of operation (mainly dedicated to task force S1 : ELMy H-mode). During that week, 23000 Pa.m^3 of gas (deuterium=98%) have been injected in the torus (94.7% via gas puffing, 5.3% via neutral beams). The results of the particle balance are presented on Table II.

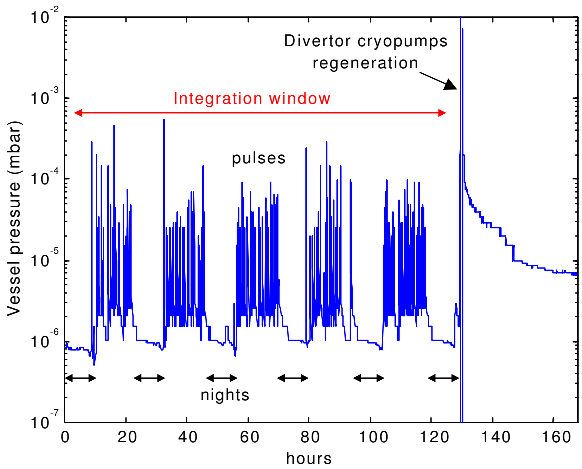

Figure 2 : vessel pressure measurement during week 26 of JET C1.

	Vessel	NBI	Divertor	Total
Pulses	80	540	12600	**13200**
Between	340	2860	4700	**7900**
Night	70	0	1010	**10800**
Total	**490**	**3400**	**18300**	**22200**

Table II : calculated gas exhaust in Pa.m^3 for week 26 of JET C1 (T_{gas} = 300°K).

The amount of particles pumped during the discharges is comparable to the amount of particles pumped between the discharges and residual outgassing during the night represents less than 5% of the total pumped particle. During its regeneration, the divertor cryo-pumps releases 19500 Pa.m^3 of gas which is in good agreement with the calculated value. Finally at the end of the week, the wall retention reaches 4%. The same analysis has been carried out over the experimental weeks of JET C1-C4 campaigns. Overall results are reported on figure 3.

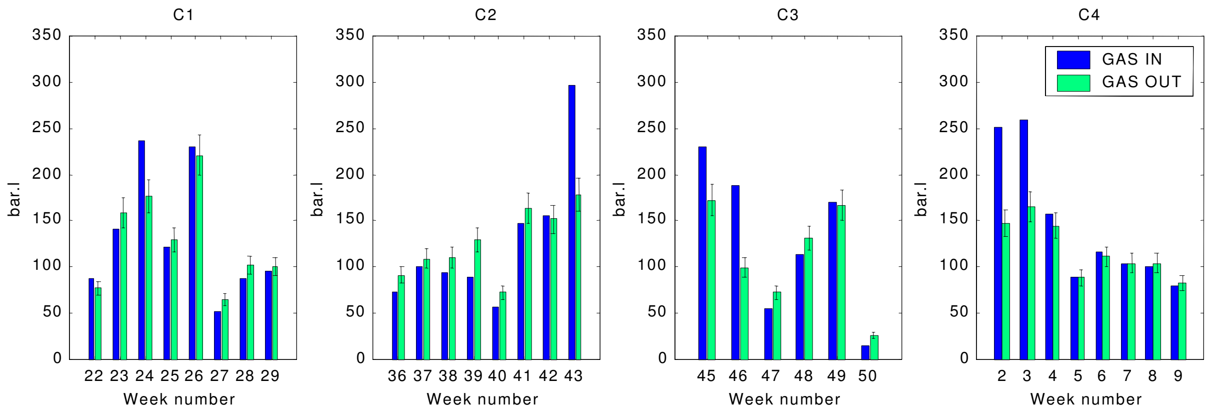

Figure 3 : gas balance results for JET C1-C4

The weekly pattern of the retention changes significantly from very high retention (up to 10000 Pa.m^3) to modest depletion (up to 2000 Pa.m^3). This behaviour appears to be coupled with the experimental program : high density H-mode discharges (TF-S1) tends to lead to high retention while optimised shear programs (TF-S2) tends to reduce the wall retention.

Finally, at the end of week 9 (C4) 1.9 10^{27} particles have been injected (since week 22) and wall retention reaches 8%. The increased retention in C4 is partly due to decreased wall temperature (320°C to 200°C), the wall reservoir must be filled up. Unfortunately, no direct comparison with other data (from AGHS) is possible but the result is consistent with previous works [4]. The present analysis is based on pressure balances calibrated in situ and thus determined by the accuracy of the gas input measurements and stability of the pressure gauges. Furthermore, it does not take into account some additional gas injections not recorded in the official JET pulses and the particle release by glow discharge. Besides the accuracy of the different measuring system (errors on $P.S$ products implicate an error of 5-10% on the retention), the importance of the later points can not be estimated presently.

5. Summary and conclusion

The pumping speeds of the different exhaust systems have been estimated for the deuterium giving access to the particle balance. During JET C1-C4, dynamic retention was generally in the range of 50% while long-term retention was around 8±10%. The method developed in this paper is easy to implement and could be a useful tool to study the wall behaviour and monitor reservoir inventories in real-time.

Acknowledgement

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References

[1] P. Andrew, et al., Fus. Eng. Design 47 (1999) 233-245.

[2] W. Obert, et al., Proc. 16 IEEE/NPSS Symp. Fus. Engineering (vol1) (1995), 742-745

[3] J. Bucalossi et al., internal report – JET (2000).

[4] P. Coad, et al., J. Nucl. Matter. 290-294 (2001) 224.