ELSEVIER

Journal of Nuclear Materials 313–316 (2003) 519–523

journal of nuclear materials

www.elsevier.com/locate/jnucmat

Static and dynamic properties of wall recycling in TRIAM-1M

M. Sakamoto [a,*], H. Nakashima [a], S. Kawasaki [a], A. Iyomasa [a], S.V. Kulkarni [b], M. Hasegawa [a], E. Jotaki [a], H. Zushi [a], K. Nakamura [a], K. Hanada [a], S. Itoh [a]

[a] *Advanced Fusion Research Center, Research Institute for Applied Mechanics, Kyushu University, 6-1 Kasuga-koen, Kasuga, Fukuoka 816-8580, Japan*

[b] *Institute for Plasma Research, Gandhinagar, Gujarat, India*

Abstract

A large difference between properties of wall recycling in the continuous gas feed case (i.e. static condition) and the additional gas puff case (i.e. dynamic condition) has been observed. In the static condition, the effective particle confinement time, τ_p^*, increases almost linearly to about 10 s during the 1 min discharge. In the dynamic condition, τ_p^* is 0.2–0.3 s during the 1 min discharge. This difference of τ_p^* is also confirmed in the ultra-long discharge. τ_p^* in the static condition becomes ~100 s before the global balance between particle absorption and release of the wall is achieved at $t \sim 30$ min. τ_p^* in the dynamic condition is, however, still on the order of ~0.3 s. The large difference between τ_p^* in the static and dynamic conditions is attributed to a reduction in the recycling coefficient due to enhanced wall pumping resulting from the gas puff.

PACS: 52.40.H

Keywords: Plasma-wall interaction; Recycling; Particle balance; Particle confinement time; Wall pumping; High Z wall

1. Introduction

Understanding of the wall recycling properties is crucial, since the operation of reactor scale machines such as ITER or a DEMO reactor will be long pulse or steady state. The wall condition, which is closely related to the wall recycling, continues to change with a long time constant during the discharge due to the plasma wall interaction. For example, strong radiation damage, which provides a new particle-trap area, occurs during the discharge [1]. Co-deposition of in-vessel elements also occurs during the discharge [2,3]. It is reported that the co-deposited material of Mo with O can retain one order of magnitude more hydrogen than normal Mo [3,4]. The temperature of the first wall increases due to the heat load from the plasma, and the temperature increase causes out-gassing from the wall. Thus, the wall recycling changes with a long time constant depending on the wall condition. However, not only the wall condition but also the plasma conditions (e.g., particle flux out of the plasma) influence the recycling properties. In such transient phenomena as edge localized modes (ELMs) or the pellet injection, the wall would contribute considerably to the pumping of the transient particle flux out of the plasma. Such dynamic responses of the wall recycling is considered to play an important role in the operation of ELMy H-mode, which is an essential operation in ITER [5]. In TRIAM-1M, it has been observed that there exists a large difference between the properties of wall recycling in the static condition (i.e. the continuous gas feed case) and the dynamic condition (i.e. the additional gas puff case). In this paper, we investigate the static and dynamic properties of wall recycling by comparing the effective particle confinement times.

* Corresponding author. Tel.: +81-92 583 7707; fax: +81-92 573 6899.

E-mail address: sakamoto@triam.kyushu-u.ac.jp (M. Sakamoto).

0022-3115/03/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
PII: S0022-3115(02)01390-9

2. Experimental results

The wall recycling properties have been studied in 2.45 and 8.2 GHz lower hybrid current drive (LHCD) discharges on TRIAM-1M ($R_{major} = 0.84$ m, $a \sim 0.12$ m, $B_t \leqslant 8$ T). The experimental conditions are as follows: the working gas is hydrogen, the RF power of 2.45 GHz LHCD is <20 kW and that of 8.2 GHz LHCD is <100 kW. The H_α line intensity, I_{H_α}, is utilized as the measure of the fueling. The applied voltage of a piezoelectric valve (i.e. the amount of the hydrogen gas supplied) is feedback controlled to match I_{H_α} with the reference signal. One of the features of the TRIAM-1M tokamak is that all of the plasma facing components consist of high Z materials, i.e. a stainless steel vacuum vessel, three sets of molybdenum poloidal limiters and molybdenum divertor plates. Low Z coating has never been done.

2.1. Static property of wall recycling

The recycling coefficient, R, i.e. the ratio of particle in-flux to particle out-flux on the plasma surface, increases with time in a static condition in which the plasma density is kept constant by continuous fueling [6]. This means that the wall gradually saturates due to accumulation of a part of particle flux out of the plasma, namely, increase in the wall inventory. In terms of R and the global particle confinement time τ_p, the effective particle confinement time τ_p^* is expressed by

$$\tau_p^* = \tau_p/(1 - R). \tag{1}$$

In both the low density ($\bar{n}_e \sim 0.2 \times 10^{19}$ m^{-3}) and the high density ($\bar{n}_e \sim 0.9 \times 10^{19}$ m^{-3}) discharges, τ_p^* increases almost linearly to about 10 s during the 1 min discharge, as shown in Fig. 1. The low density and high density plasmas are sustained by 2.45 and 8.2 GHz LHCD, respectively. The values of τ_p are ~14 ms for the low density plasma and ~6 ms for the high density plasma. The denominator of the right hand side of Eq. (1) is so small that τ_p^* is sensitive to a slight change in R, since R is close to 1 (see Ref. [6]). In order to confirm the validity of the estimation of τ_p^* using Eq. (1), a fueling termination experiment was carried out, since the value of τ_p^* can also be estimated from the decay time of the plasma density after the external fueling is stopped. In Fig. 2, the time evolution of the line averaged electron density, $\bar{n}_e$, of the 2.45 GHz LHCD plasma is shown. The external fueling is stopped at the time indicated by the arrow in the Fig. 2 ($t \sim 33.2$ s). The decay time of $\bar{n}_e$ is ~4 s and it is consistent with the result of Fig. 1. The decay time, τ_d, is estimated from fitting the data to the function; $C_1 + C_2 \exp[-(t - t_1)/\tau_d]$, where C_1 and C_2 are fitting parameters, and t_1 is the time of the fueling termination.

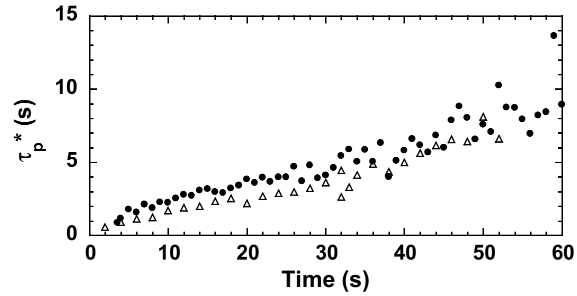

Fig. 1. Time evolution of the effective particle confinement times for the low density ($\bar{n}_e \sim 0.2 \times 10^{19}$ m^{-3}, •) and the high density ($\bar{n}_e \sim 0.9 \times 10^{19}$ m^{-3}, △) discharges.

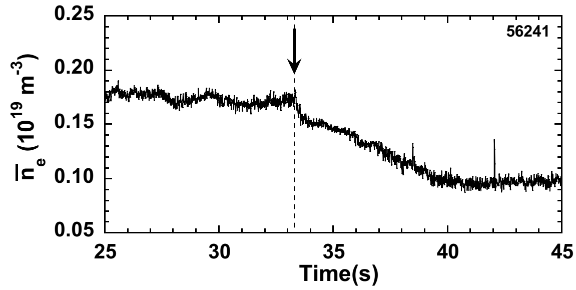

Fig. 2. Time evolution of the line averaged electron density. The external fueling was stopped at the time indicated by the arrow. The plasma is sustained by 2.45 GHz LHCD.

2.2. Dynamic property of wall recycling

To investigate the dynamic property of wall recycling, we carried out additional gas puff at intervals of ~5 s in the 2.45 GHz LHCD plasma with the duration of 1 min, as shown in Fig. 3(a). Fig. 3(b) is enlarged from $t = 44$ to 48 s. The piezoelectric valve for the feedback control is automatically closed just after the gas puff because I_{H_α} increases above the reference level of the feedback control. There is no fueling in the period from the time of the gas puff to the time of the fueling restart, which is indicated by the arrow in Fig. 3(b). Accordingly, the decay time of $\bar{n}_e$ just after the gas puff gives the effective particle confinement time, which is ~0.27 s in the case of Fig. 3(b). The time trace of I_{H_α} is similar to that of $\bar{n}_e$ but the decay time of I_{H_α} is ~0.33 s.

The time evolution of τ_p^* estimated from the decay time of $\bar{n}_e$ is shown in Fig. 4. The data of three discharges are drawn in the figure. During the discharge, the effective particle confinement time is almost constant with a value of 0.2–0.3 s with an error of ~20%, and is one order of magnitude less than the effective particle confinement time in the static condition (see Fig. 1).

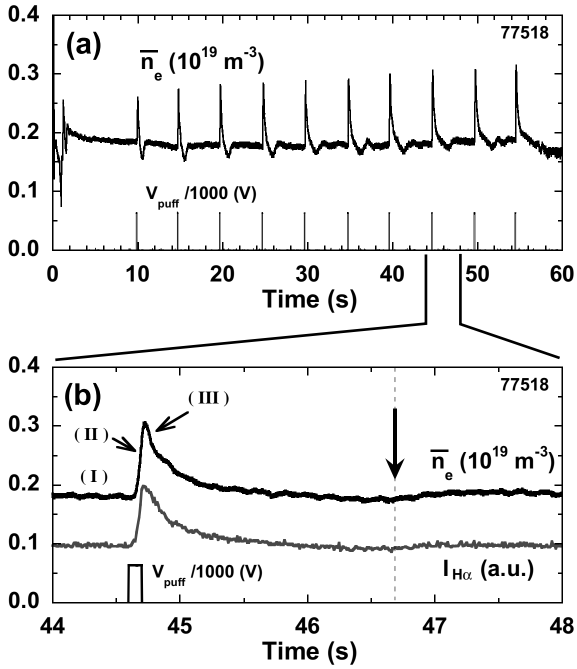

Fig. 3. (a) Time evolution of the line averaged electron density, and the voltage applied to the piezoelectric valve for the external fueling. (b) The decay of the line averaged electron density and the H_α line intensity after the gas puff. An arrow indicates the time that the fueling restarts.

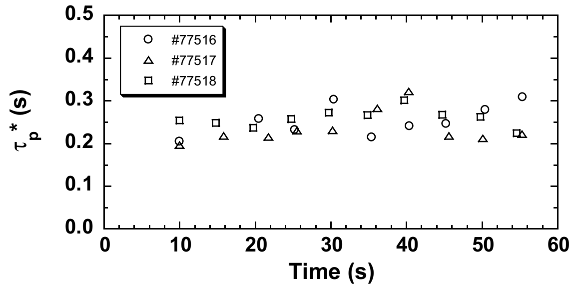

Fig. 4. Time evolution of the effective particle confinement time in the dynamic condition. τ_p^* is estimated from the decay time of $\bar{n}_e$ after the gas puff.

2.3. Static and dynamic properties of wall recycling in the ultra-long discharge

Recently, ultra-long discharges with the duration of longer than 3 h were achieved in TRIAM-1M [7], although the density was low ($\sim 10^{18}$ m^{-3}). In the longest discharge, with the duration of 3 h 10 min (11 406 s), I_{H_α} spontaneously increased above the reference level at $t \sim 30$ min as shown in Fig. 5(a) and then the fueling automatically stopped. At that time, global balance between the wall absorption and the hydrogen release from the wall was achieved, and the plasma density was maintained by the recycling hydrogen alone until the end of the discharge. For this long duration discharge, we carried out the gas puff at $t \sim 15$ and ~ 23 min to examine the dynamic property of the wall recycling. As shown in Fig. 5(b) and (c), the decay times of I_{H_α} are 0.24 and 0.33 s, respectively. We do not have $\bar{n}_e$ data for this discharge but τ_p^* is expected to be similar to the decay time of I_{H_α} from the result of Fig. 3(b). This decay time is the same as that of the initial phase of the discharge shown in Fig. 4 even though the wall inventory increases with time.

On the other hand, in order to examine the static property of the wall recycling, we decreased the reference level by 8.5% at $t \sim 26.7$ min as shown in Fig. 5(a). The gas fueling was automatically stopped and I_{H_α} decreased very slowly with a time constant of ~ 130 s as shown in Fig. 5(d). The effective particle confinement time is deduced to be on the order of 100 s at $t \sim 26.7$ min. At $t \sim 30$ min, the effective particle confinement time is infinity because the plasma density is maintained by the recycling hydrogen only. It is apparent again that the static property of the wall recycling changes with time (i.e. the wall inventory) in contrast to the dynamic property.

3. Discussion

A large difference between τ_p^* for the static and dynamic conditions was experimentally observed. There are two possibilities for explaining this difference: the degradation of τ_p due to the increase in the plasma density as a result of the gas puff, or a change in the wall recycling. The reduction of τ_p due to the additional gas puff is evaluated to be $\sim 30\%$ from the τ_p scaling obtained in another density-scan experiment in TRIAM-1M. This reduction cannot explain the large difference between τ_p^* for the static and dynamic conditions, but it contributes to the reduction of τ_p^*. Note that the time constant of the external pumping is ~ 2.4 s. It is defined as the decay time of the neutral pressure after the hydrogen gas is supplied in the vacuum vessel without the plasma. The external pumping is considered not to affect the effective particle confinement time because the time constant of the external pumping is rather different from τ_p^* for the static and dynamic conditions.

Now, we discuss the change in the wall recycling property due to the gas puff focusing on the net wall pumping rate Γ_{wall} which is estimated from the following equation:

$$dN_H^0/dt + dN_H^p/dt = \Gamma_{fuel} - \Gamma_{pump} - \Gamma_{wall}, \qquad (2)$$

where N_H^0 is the total number of hydrogen neutral atoms in the vessel, N_H^p the total number of hydrogen ions in the plasma, Γ_{fuel} the fueling rate, Γ_{pump} the pumping rate

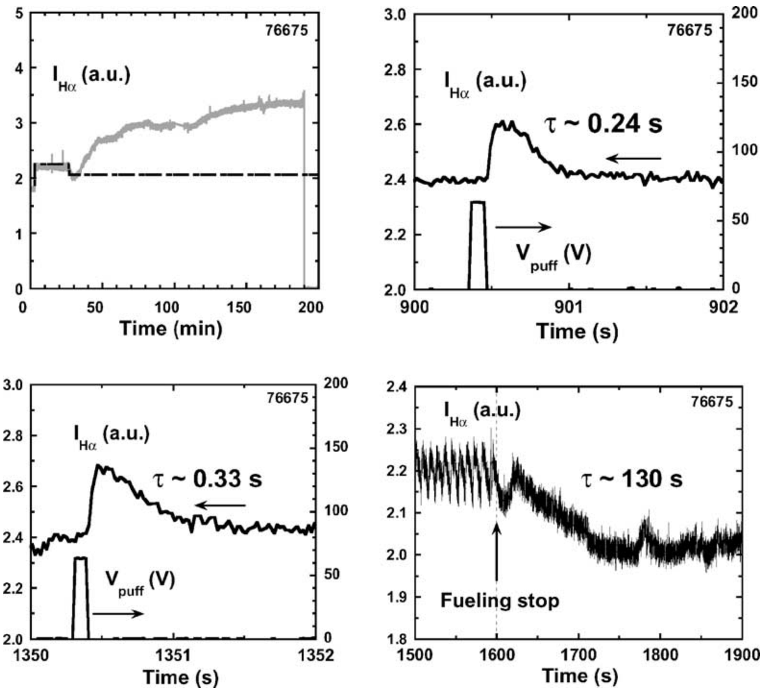

Fig. 5. (a) Time evolution of the H_α line intensity in 3 h 10 min discharge. The chain line indicates the reference level of the feedback control. (b) and (c) the decay of the H_α line intensity after the gas puff. (d) the decay of the H_α line intensity after the fueling is stopped.

by the external pump-unit, and Γ_{wall} is the balance between absorption rate and release rate of the wall. The first term of the left hand side of Eq. (2) is deduced from the data of the ionization gauge at the pumping duct. N_H^p is assumed to be same as N_e, namely, $Z_{eff} = 1$ is assumed. Γ_{fuel} is estimated from the voltage applied to the piezoelectric valve. Γ_{pump} is the product of the neutral pressure and the pump speed of the external pump-unit. The unknown parameter Γ_{wall} can be obtained from the above equation. The plasma density is assumed to have a parabolic profile and the neutral gas region is assumed as the volume of the vacuum chamber except the plasma volume.

In order to compare Γ_{wall} for the static and dynamic conditions, the time evolution of $\bar{n}_e$ shown in Fig. 3(b) is divided into the following phases: (I) the static phase, (II) the phase during the gas puff (i.e. increase in $\bar{n}_e$), (III) the phase just after the gas puff (i.e. decay of $\bar{n}_e$). The net wall pumping rate in each phase is $\sim 5 \times 10^{17}$ atoms/s for the phase (I), $\sim 1 \times 10^{19}$ atoms/s for the phase (II), $\sim 2 \times 10^{18}$ atoms/s for the phase (III). It is found that Γ_{wall} in the dynamic condition (i.e. during and just after the gas puff) is much higher than that in the static condition, namely, the wall pumping is enhanced due to the gas puff. It is proposed that the recycling coefficient decreases in the dynamic condition due to increased wall pumping, and that the large difference between τ_p^* in the static and dynamic conditions is as a result of the reduction in R. It is considered that the enhanced wall pumping is caused by the increase in the diffused ion and charge exchange neutral fluxes from the plasma to the wall due to the additional gas puff.

4. Conclusion

The static and dynamic properties of the wall recycling have been investigated by comparing the effective particle confinement time. In the static condition (continuous gas feed case), τ_p^* increases almost linearly to about 10 s during the 1 min discharge. On the other hand, τ_p^* is 0.2–0.3 s during the 1 min discharge in the dynamic condition (additional gas puff case). This difference in τ_p^* between the static and dynamic conditions is reproduced in the ultra-long discharge. τ_p^* in the static condition becomes $\sim$100 s before the global balance between particle absorption and release of the wall is achieved at $t \sim 30$ min. τ_p^* in the dynamic condition is, however, still on the order of $\sim$0.3 s. From the analysis of the particle balance in the vacuum vessel, it is found that the wall pumping is enhanced during and just after the additional gas puff. The large difference between τ_p^* in the static and dynamic conditions is attributed to the reduction of R due to the enhanced wall pumping associated with the gas puff.

References

[1] T. Hirai et al., J. Nucl. Mater. 258–263 (1998) 1060.
[2] R. Behrisch et al., J. Nucl. Mater. 233–237 (1996) 673.
[3] T. Hirai et al., J. Plasma Fusion Res. Ser. 3 (2000) 284.
[4] T. Hirai et al., J. Nucl. Mater. 283–287 (2000) 1777.
[5] Y. Shimomura et al., Nucl. Fusion 41 (2001) 309.
[6] M. Sakamoto et al., Nucl. Fusion 42 (2002) 165.
[7] M. Sakamoto et al., J. Plasma Fusion Res. Ser., 5 in press.