PARTICLE FUELLING AND RECYCLING IN DISCHARGES WITH RADIATION COOLING AND IMPROVED CONFINEMENT IN TEXTOR-94

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1. Introduction

The concept of a cold radiating plasma mantle is considered as a possible solution for the problem of power exhaust from reactor grade fusion plasmas. However, at the same time plasma operation at high densities and good energy confinement are necessary to ensure ignition. The *Radiative Improved Mode* (RI-mode) obtained at TEXTOR-94 combines radiative cooling of the plasma edge and improved energy confinement at high plasma densities [1]. The confinement improvement observed in RI-mode discharges has been attributed to the suppression of Ion Temperature Gradient driven instabilities due to the presence of the impurities and the steepening of density profiles typical for the RI-mode [2]. Nevertheless, the substantial changes at the plasma edge due to the radiating mantle are important requirements to obtain the transition to RI-mode [3]. This contribution describes the characteristic changes of the recycling and fuelling properties occurring when the radiating mantle is formed.

2. Experimental set-up and data evaluation

In this paper we focus on discharges with a plasma current of I_p=400 kA and a toroidal field of B_T= 2.25 T (q_a=3.2) heated with neutral beam co-injection and ion cyclotron resonance heating (P_{heat}= 2.5 MW) under boronized wall conditions at densities close to the Greenwald density. Neon is added to establish the radiating boundary. Optical diagnostics are used to measure electron density and temperature profiles at the edge as well as particle fluxes at the main toroidal limiter ALT-II, the inner bumper limiter and the penetration of neutrals into the plasma from a carbon test limiter inserted into the limiter lock of TEXTOR-94. The flux distribution can be determined from measurements with a CCD camera equipped with a D_α filter observing a poloidal cross section of TEXTOR-94 [4]. With respect to deuterium fluxes, the substantial contribution of molecules to the total neutral flux has been taken into account for the ratio between ionisation and excitation rate coefficients S/XB relating the ionisation source to photon emission (see ref. [3] for details). The global recycling behaviour is analysed on the basis of measured quantities using the particle balance equation

$$\frac{dN_P}{dt} = \frac{N_P}{\tau_P} + f\Gamma_{rec} + f_{ex}\Gamma_{ex} = \Gamma_{ex} - \Gamma_{pump,tot} \qquad (1)$$

where N_P is the total number of deuterium ions (determined from the measured electron content and corrected for the dilution measured with charge exchange recombination spectroscopy), Γ_{rec} the total recycling flux, Γ_{ext} the external fuelling rate (gas injection and the beam fuelling), f and f_{ext} the fuelling efficiency for recycling and injected neutrals, respectively. $\Gamma_{pump,\,tot}$ is the particle flux pumped by the wall and the pump limiter ALT-II where the latter one has been determined from the neutral pressure in the pumping ducts to separate the effect of the wall pumping. Modelling of the recycling of neutrals at the limiters and the penetration of atoms and molecules into the confined volume has been performed with the 1D RITM- code [5]. The B2- Eirene code has been used to model the recycling and fuelling characteristics in a more realistic 2D geometry taking into account the main toroidal limiter ALT-II and the bumper limiter on the inboard side of TEXTOR-94 [6].

3. Results and discussion

The total recycling flux is dominated by the main ALT-II limiter. Measurements of the D_α emission in a poloidal cross section show a halo of neutrals caused by charge exchange and extending around the limiter in poloidal direction. This halo is not seen by the local flux measurements and amounts to about 30% of the photon emission for high densities and without neon injection (cf. [4]). The flux from the inner bumper limiter is less than 10% of the flux at ALT-II under these conditions. When the fraction γ of the radiated power with respect to the total input power is increased by neon injection, the importance of the recycling at the bumper limiter is increasing.

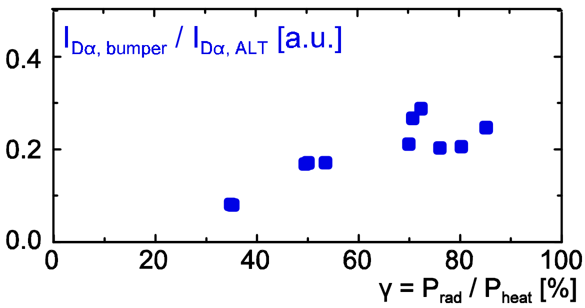

Fig. 1: D_α emission at the inner bumper limiter relative to emission at ALT-II as a function of γ= P_{rad}/ P_{heat}

Fig.1 illustrates these findings showing the intensity ratio of D_α emission measured at the bumper and the ALT-II limiter. These data are taken into account for the calculation of the total recycling flux. The behaviour is interpreted as a reduction of the local recycling at ALT-II compared to the bumper limiter due to an increased fuelling efficiency as discussed in the next section.

The fuelling efficiency relates the fraction of neutrals ionized inside the LCFS to the total flux starting from the plasma facing components. It can be determined experimentally from the measured distribution of line emission and using the proper S/XB factors to convert line emission into ion source distribution. From a 2D observation (radial/ toroidal plane) of a carbon limiter positioned at the LCFS we determine an increase of the ratio between ionisations inside the LCFS and the total ionisations from 0.58 to 0.76 going from γ=35% (L-mode) to γ=85% (RI-mode). The penetration depth is a measure of the radial extent of the ion source distribution inside the LCFS and increases from about 1.5 cm to 2 cm (cf. also [3]). However, in addition to ionisation in the scrape-off layer the fuelling of neutrals is further reduced by charge exchange losses. The 1D modelling shows that about 25% of the neutrals starting at the limiter are coming back to the surface as neutrals independently of γ. The 2D modelling with the B2-Eirene code has been performed for r/a> 0.65 including the scrape-off layer and using the density and the radial heat flux at the inner edge of the computational grid as boundary conditions for a L-mode discharge (γ=35%) and a RI-mode discharge (γ=85%). The power loss by radiation has been inferred from the measured radiation profiles. The anomalous particle transport has been modelled using a Bohm-like diffusion coefficient. The percentage of ionisations inside the LCFS increases from 44% to 67% going from L- to RI-mode confirming the experimental results that in the RI-mode the fuelling efficiency of recycling neutrals is substantially improved.

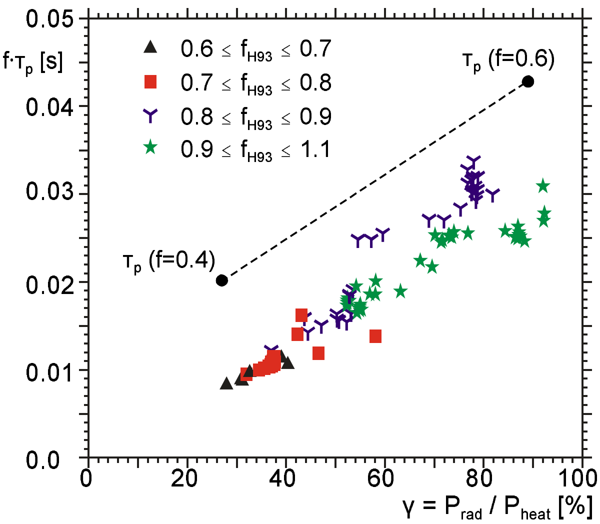

Fig. 2: Product of particle confinement time and fuelling efficiency as a function of γ

As seen in the modelling the measured recycling flux strongly decreases with increasing radiation, the total flux reduces from about $3\text{x}10^{22}$/s at γ=35% to less than 10^{22}/s at γ=85%. The recycling flux is much larger than the external fuelling rate and the rate dN_P/dt. Therefore, the product between particle confinement time and fuelling efficiency of recycling neutrals can be given by $f\tau_p = N_P/\Gamma_{rec}$ (cf. Equ. 1, note the factor f in this expression). This quantity is shown in fig. 2 and increases with γ according to the reduction of Γ_{rec}. If we allow an increase of f from about 0.4 to 0.6 as indicated by our experimental results and the B2-Eirene modelling, we still find an increase of the particle confinement time by about a factor of 2 comparing L- and RI- mode as indicated by the dashed line.

Fig. 3a) shows the time traces of the external fuelling rates from beam and gas puff (both dashed), the flux pumped by ALT-II, the derivative of the particle content and the total flux pumped by the wall and ALT-II (all solid) as deduced from Equ. (1) for a L-mode discharge (γ=35%). The external gas puff necessary to maintain the preset value of the density continues up to t=4.0 s when the density feed back has been switched off. It can be seen that most of the particles injected through the gas valve are pumped by the wall. After the closure of the gas valve the flux pumped by ALT-II is somewhat larger than the global pump rate indicating a particle release from the wall. Fig. 3b) shows these quantities for a RI-mode discharge, where the neon injection started at t=1.5 s. With the injection of neon the external gas puff is switched off and the discharge is only fuelled by the neutral beam. These findings are typical for the application of radiation cooling. Improved fuelling efficiency of recycling neutrals and increased particle confinement time lead to a reduction of the external gas rate necessary to maintain the high density. As the particles puffed in have a very low fuelling efficiency and the edge density increases at high puffing rates, the reduction of the gas puff amplifies the reduction of the edge density already caused by the reduction of transport out of the confined volume caused by the radiation cooling. This supports the density peaking which contributes to the suppression of

ITG-modes in the RI-mode. Strong gas puffing leads to a decrease of the energy confinement. In this context the influence of the positioning of the plasma column on the recycling and confinement properties in the RI-mode must be considered. Shifting the plasma column to the low field side improves the energy confinement, since localized recycling at the inner bumper limiter and subsequent wall pumping are reduced minimizing the need for external gas flow.

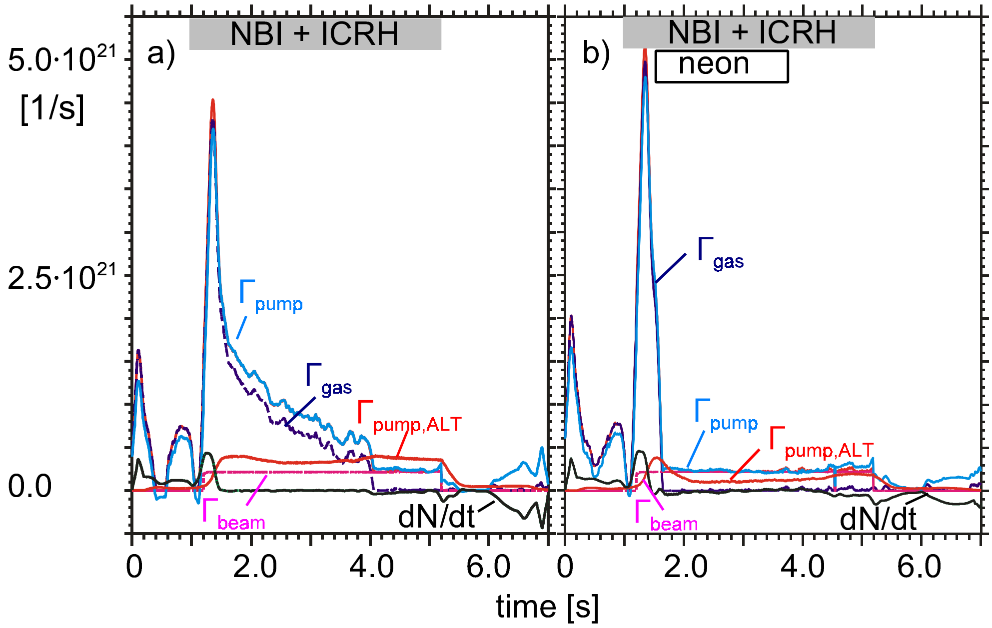

Fig. 3: External fuelling (beam and gas puff) and pumping rates (pump limiter ALT-II and total pumping rate): a)L-mode b) RI-mode

4. Summary and conclusion

Spectroscopic studies of the recycling and fuelling properties have shown a substantial reduction of the recycling flux and an improvement of the fuelling efficiency at the plasma edge with increasing radiation. The resulting decrease of the external gas fuelling rate supports the steepening of the density profiles in the RI-mode.

5. References

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