*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-1.041 (2002)*

Particle transport in ASDEX Upgrade discharges undergoing strong density peaking

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1. Introduction Recent results in ASDEX Upgrade indicate that the microwave turbulence can be responsible for both heat and particle transport, and that therefore the assumption $D \propto \chi$ can be used to reproduce the experimental density profiles. This model has been successfully applied to several high density scenarios. Aim of this paper is to present an application of this model to pellet fuelled shots, in order to investigate the dependence of particle transport on heat flux during the density decay after pellet injection.

Pellet fuelling experiments have been performed in ASDEX Upgrade with an injection set up allowing for enhanced pellet launch speed from the high field side [1]. In these experiments trains of pellets have been injected from the HFS in H-mode scenario. Strongly peaked density profiles have been obtained when strong pumping is applied.

The ratio between D and χ has been evaluated for the stationary H-mode and during the density decrease which follows the last pellet injection. These results have been compared with those previously obtained from the application of the same model.

2. Dependence on heat flux profile of pellet induced density peaking.

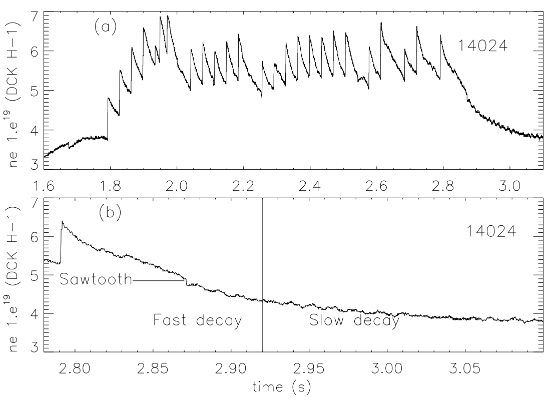

Figure 1: *(a) density time trace (b) density decay after last pellet injection*

The two analysed shots 14023 and 14024 have a similar plasma configuration: the Hydrogen plasma, with low averaged triangularity $< \delta > \approx 0.2$, $I_p = 0.8$ MA, reaches the H-mode confinement heated by 6 MW of NBI. After reaching the ELMy H-mode confinement a train of Deuterium pellets, with a repetition rate of 30 Hz, has been injected from the HFS (Fig.1a). The main difference between these two discharges is the velocity of injected pellets, which is low ($v_p \approx 240$ m/s) in the 14023 shot and high ($v_p \approx 480$ m/s) in the other one. After the launch of the last pellet the density starts decreasing: usually for a few milliseconds the decay has mainly a convective nature related to the presence of strong ELMs [2]; after this fast phenomenon a density decay takes place, which is mainly of diffusive nature. In these discharges the post-pellet decay is not totally diffusive, due to a sawtooth event occurring about 60 ms after the density peaking.

Two different time scales are associated to the diffusive density decay [3], which is fast over a time interval of about 100 ms and then slows down (Fig.1b). The particle transport is modified by the pellet injection [3]: the particle diffusivity D_p reproducing the fast density decay is about 1.5 times higher of the diffusivity D_H which characterises the H-mode plasma and the slow density decay. In order to investigate the dependence of density profiles on heat flux we adopted the model presented in [4]: the heat conductivities χ_e and χ_i are calculated from power balance and averaged, obtaining the experimental χ_{eff}. This parameter is assumed to be representative of the turbulent energy transport of the plasma.

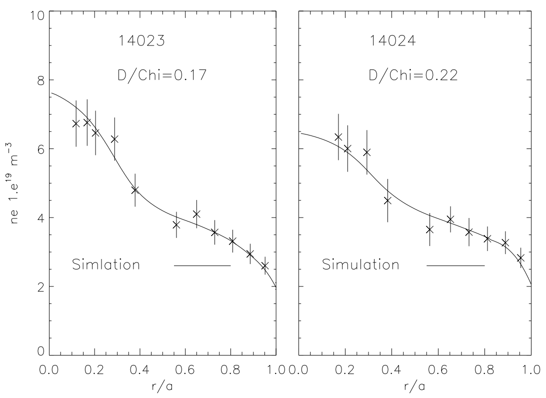

Figure 2: *Comparison of simulated H-mode stationary density profiles with Thomson scattering data.*

Predictive simulations have been carried out using $D \propto \chi_{eff}$ and as pinch velocity the neoclassical Ware pinch. These simulations are restricted to the core of plasma ($r_{tor} \leq 0.8$) keeping the density profile equal to the experimental one in the edge region. The proportionality coefficient between D and χ_{eff} has been adjusted to match the experimental data of Thomson scattering. The effect of the sawtooth has been taken into account using a reconnection model which mainly flattens the density profile inside the inversion radius. The code used in all the simulations presented here is ASTRA transport code [5].

The proportionality coefficient has been evaluated for the H-mode density profiles. These stationary profiles can be reproduced using $D = (0.17 \pm 0.03)\chi_{eff}$ for the shot 14023 and a slightly higher value $D = (0.22 \pm 0.03)\chi_{eff}$ for the shot 14024 (Fig.2).

The model has then been applied after the injection of the last pellet: the analyses skipped about 20 ms after the density peaking because of the convective nature of the transport phenomena in this time interval.

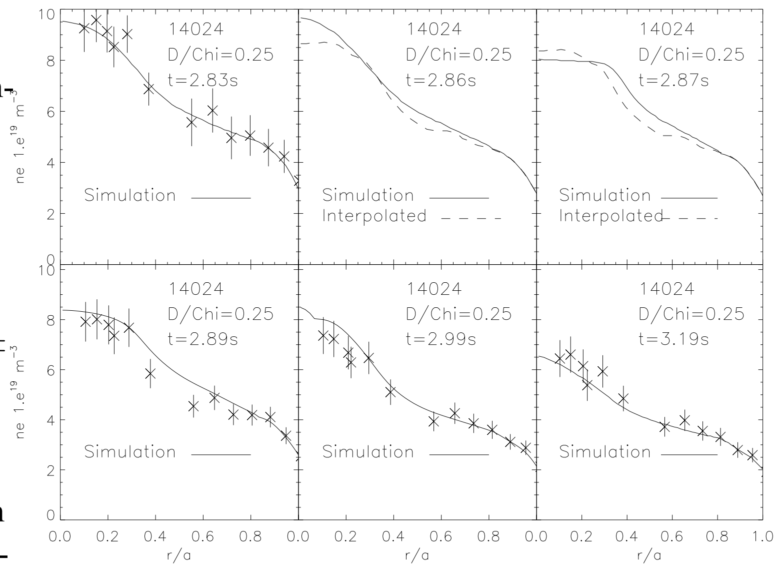

Figure 3: *Comparison of simulated density profiles with Thomson scattering data after the injection of last pellet.*

The simulations showed a good agreement between experimental and calculated profiles when the model, using the pre-pellet proportionality coefficient, is applied to the slow decay phase. Two times higher valuess are required to reproduce the density decay during the fast decay phase, although for the shot 14024 it is possible to obtain results in agreement with the experimental data using a single proportionality coefficient, equal to 0.25, for both phases(Fig.3). The two pictures at t=2.86s and at t=2.87s show the calculated density profiles just before and just after the action of the reconnection model; ASTRA interpolated profiles (dashed lines) are shown for comparison.

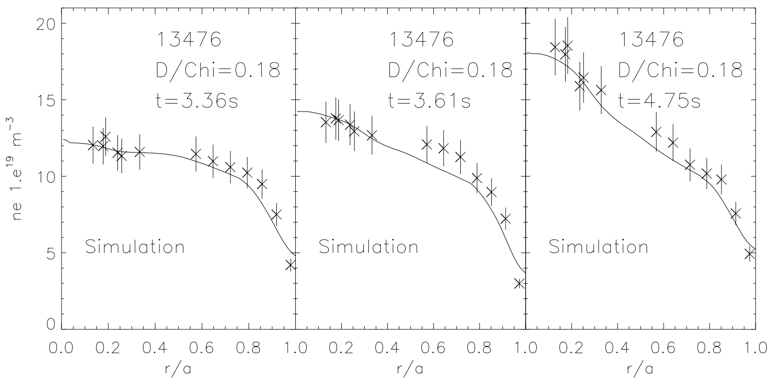

Figure 4: *Comparison of simulated density profiles with Thomson scattering data*

These results indicate that an extra particle transport mechanism is working during the fast decay phase with respect to the unperturbed H-mode and the slow decay phase: one hypothesis is that the reconnection model is not able to completely take into account the effect of the singular strong sawteeth happening at the middle of the fast decay phase.

3. Dependence on heat flux profile of spontaneous density peaking

Spontaneous peaked density profiles have been observed in ASDEX Upgrade as a consequence of applying long, strong and constant gas puff to a NBI heated, type 1 ELMy H-mode [4]. Substituting half of the NBI with central ICRH and keeping all the other parameters almost unchanged the density profile keeps itself flat, but also the all amount of NBI and additional ICRH leads to flat density profiles. This implies that the particle fuelling of the NBI, which is unchanged, is not the only reason for the peaking.

These experimental results suggest that a relation exist between particle and energy transport. Due to the stiffness of temperature profile, the plasma core of central ICRH heated shots is characterised by higher values of heat conductivity with respect to NBI heated shots, where the heat deposition profile is almost flat. If the particle and energy turbulent transport are related, higher values of particle transport can be expected in ICRH heated shots and this could explain the flattening of density profiles.

Two examples of these different heating scenarios have been previously analysed in [4]: the shot 13476, heated by 5 MW of NBI and characterised by a strong density peaking and the shot 13660, heated by 2.5 MW of NBI in combination with 2.5 MW of central ICRH, which has an almost flat density profile. Both these plasmas are in Deuterium, they have high values of triangularity $\delta = 0.3$, $I_p = 1MA$ and confinement properties better than the pellet fuelled shots presented in the previous paragraph. The simulations showed that these two cases can be well modelled assuming $v_p = 1.5 v_{Ware}$ and $D = 0.12\chi_{eff}$, namely with a proportionality coefficient equal to one half of that used for the pellet fuelled shots.

A deeper analysis of these discharges indicates that the neoclassical ion energy conductivity

χ_{neo} [6] accounts for about one half of the total energy transport, therefore the turbulent energy transport can be better described by the parameter $\chi_{eff}^{turb} = (\chi_e + \chi_i - \chi_{neo})/2$. The neoclassical transport is negligible for the analysed pellet fuelled shots, then χ_{eff}^{turb} and χ_{eff} coincide for these discharges.. The simulations have been performed allowing D to be proportional only to the anomalous thermal conductivity χ_{eff}^{turb}: as shown in Fig.4 and in Fig.5 a proportionality coefficient of about 0.2 is required to describe the shape and the temporal evolution of density profiles. These results are in better agreement with those obtained analysing the pellet fuelled shots; they indicate that several different scenarios can be reproduced without a significant variations in the ratio D/χ and without introducing anomalous inward pinch terms, though an high level of incertitude is still present in the estimation of χ_{eff}^{turb}.

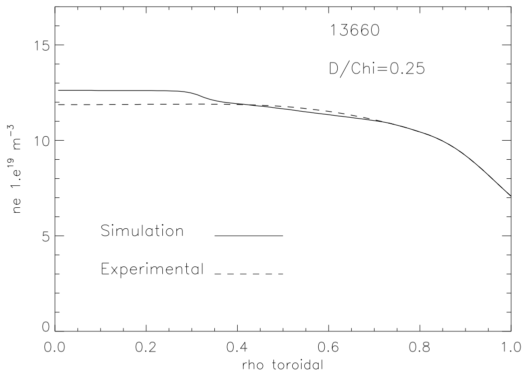

Figure 5: *Comparison of experimental (deconvolution from interferometer and Li beam data) and simulated profiles*

4. Conclusions The dependence of particle transport on heat flux for pellet fuelled shots has been investigated: a rather simple model using $D \propto \chi$ has been applied and the proportionality coefficient has been evaluated.

The simulations indicate that the same proportionality coefficient, equal about to 0.2, can be used to reproduce the stationary H-mode density profile and the slow density decay after pellet injection, though we have same difficulties to treat the first 100 ms of density decay characterised by a strong singular sawtooth. This coefficient became two times lower when the model is applied to the spontaneous density peaking observed when NBI heating in combination with strong gas puff is used. A refinement of this model is proposed, in which the ion neoclassical conductivity is subtracted from the experimental χ_{eff}, in order to obtain a particle diffusion coefficient D proportional only to the turbulent part of heat conductivity χ_{eff}^{turb}. This correction, which is important mainly in high density discharges, allows us to reproduce the evolution of spontaneous and pellet induced peaked density profiles without a strong variation in the ratio D/χ.

References

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