TRANSPORT ANALYSIS OF THE EDGE PLASMA IN H MODE DISCHARGES OF ASDEX UPGRADE

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ABSTRACT. Profiles of the electron heat diffusivity χ_e and the ratio v_{in}/D in the steep gradient zone and in the core of high-density H-mode discharges are determined by transport analysis using a special version of the 1.5-D BALDUR code. It is found that the reduction of χ_e is strongest near the inner boundary of the steep gradient zone where it reaches a factor of 4. The v_{in}/D profile significantly rises at the edge which causes the steep density decline measured. No degradation of energy transport in the bulk plasma is seen when the density limit is approached.

Introduction

The energy and particle transport in the edge region of two high density H-mode discharges of ASDEX Upgrade is explored. In addition, the bulk transport is analysed and compared with the results from the periphery. Such investigations are feasible now, because the electron temperature and density profiles in the steep gradient zone have been measured with sufficient spatial resolution. Long-term objectives of this study are to develop more comprehensive scaling relations for transport coefficients and to improve the modeling of the steep gradient zone. It is planned to apply these results in simulations of current tokamaks and reactor grade devices like ITER.

Transport Model

The simulations are carried out with a special version of the 1.5-D BALDUR transport code [1,2,3] which also includes a scrape-off layer (SOL) modeling. In the confinement zone, empirical electron and ion heat diffusivities $\chi_e = \chi_i = \chi$, a diffusion coefficient D = 0.6 χ_e and an inward drift velocity $v_{in} = C_v 2xD/(\rho_w x_s^2)$ are used [3]. A new scaling law for the effective heat diffusivity χ in high-density ELMy H-mode plasmas is applied [4]. It is compatible with the ITERH92-P ELMy H-mode scaling of the thermal energy confinement time [5] and has been validated against three JET and three DIII-D discharges from the ITER Profile Database, covering a wide parameter range, and against ASDEX Upgrade discharges. The coordinate x is the effective radius of a flux surface ρ normalized to the effective radius of the wall contour ρ_w and $x_s = \rho_s/\rho_w$ denotes the separatrix. In the calculations the separatrix is located at $x_s = 0.89$. The dimensionless factor C_v provides a measure of the peakedness of density profiles.

The radiative loss due to carbon is calculated by an impurity radiation model that solves rate equations for all ionization stages and takes into account an impurity transport with the anomalous coefficients $D_I = \mathrm{D}$ and $v_{in,I} = v_{in}$. In the SOL, the deuteron flow along the magnetic field is computed with a Mach number M_D whose value is chosen such that the neutral density at the separatrix matches the value determined from low energy neutral flux spectra [6]. The cross-field transport coefficients in the SOL are set $\chi_e = \chi_i = 1.5\ m^2 s^{-1}$ and D = $0.9\ m^2 s^{-1}$, so that the measured temperature and density fall-off lengths are obtained.

The time evolution of the line averaged density in the discharge is prescribed in the calculations. A density feedback is applied which controls the influx of deuterium atoms. The neutral sources and the neutral density and temperature profiles are computed by a Monte Carlo code. Detailed transport analyses are feasible in the steep gradient zone, because the calculations are carried out on a non-equidistant grid with good spatial resolution.

Results and Discussion

The first H-mode discharge analysed is No. 7978 with $\bar{n}_e = 7.6\times10^{19}\ m^{-3}$, $I_p =$ 1.2 MA, $B_t = 2.5$ T and $P_{NI} = 5.0$ MW ($D^0 \rightarrow D^+$). The influence of the Type I ELMs is taken into account in a time-averaged manner. Transport analysis is carried out under quasi-stationary conditions, so that only profiles of the v_{in}/D ratio can be determined in the interior plasma and in the steep gradient zone. The corresponding χ_e profiles are inferred from electron temperature measurements. In the calculations, the influx rate of carbon is adjusted such that the experimental Z_{eff} value of 1.7 is reached. Both the measured and the computed Z_{eff} profiles are flat. The radiative loss from closed flux surfaces is required for correctly computing the conductive heat flux and the electron temperature at the separatrix which is used to fix the separatrix position with the help of the measured temperature profile. At the nominal separatrix position, one measures $T_e = 190\ eV$ which significantly exceeds the computed separatrix temperature of 84 eV. The measured and calculated temperatures are found to coincide if the separatrix is shifted outward by 1 cm in the midplane.

The main results obtained at 3 s are given in Figs 1 to 4. Figure 1 shows the profiles of the electron density measured by DCN interferometry and Li-beam diagnostic (dashed curve), of the computed electron and deuteron density (solid curves) and of the corresponding v_{in}/D ratio required. Obviously, the flat electron density profile in the core is well modeled by the small v_{in}/D values resulting from the v_{in} scaling with $C_v = 0.2$. By contrast, the steep density decline measured in the edge zone is incompatible with the v_{in}/D ratios (dotted line) predicted by the v_{in} scaling. A good modeling is only achieved by the strongly rising v_{in}/D profile given. The electron temperature profile measured by ECE diagnostic (crosses) and Thomson scattering (squares), the calculated electron and ion temperature profile and the χ_e profile are plotted in Fig. 2. As can be seen, the scaling law for χ accurately predicts the electron temperature profile in the interior plasma. Moreover, the computed total energy agrees with the experimental W_{MHD} value of 656 kJ.

These results are consistent with the $H_{ITER89P}$ value of 1.6. Note that a very high temperature pedestal occurs in the steep gradient zone where χ_e is significantly reduced. Results from detailed transport analyses in the edge region are presented in Figs 3 and 4. The coordinate r is the minor half-axis of a flux surface and $r_s = 50$ cm denotes the separatrix position in the midplane. In Fig. 3, the measured (dashed curve) and computed electron density profiles are depicted. Extremely high v_{in}/D values, already given in Fig. 1, are found. A special treatment is necessary in the zone $r_s - 6cm \leq r \leq r_s$ in the midplane (corresponding to $0.76 \leq x \leq x_s$). Analysis of the experimental temperature profile $T_e(r)$ (see Fig. 4) showed that a detailed evaluation of $\chi_e(r)$ has to be carried out in the steep gradient zone of width $\Delta = 4$ cm, i.e. in the range $r_s - \Delta \leq r \leq r_s$ (corresponding to $0.80 \leq x \leq x_s$). The reduction of χ_e required is found to be space dependent. It is strongest near the inner boundary of this zone (see also Fig. 2), where it reaches a factor of 4. The heat diffusivities are evaluated with an accuracy of about ±20 %. Note that the electron heat diffusivity is still anomalous, because the neoclassical χ_e values are two orders of magnitude smaller. We conclude that turbulence is reduced but not totally suppressed.

The second H mode discharge studied is No. 7649 with $\bar{n}_e = 8.5\times10^{19}\ m^{-3}$, $I_p = 1.0$ MA, $B_t = 2.5$ T and $P_{NI} = 5.0$ MW ($D^0 \rightarrow D^+$). It was selected because it is close to the density limit. The measured density profile is flatter than in the first shot and is well modeled in the bulk by the v_{in} scaling with $C_v = 0$. In the edge zone, the v_{in}/D profile is found to rise strongly as with the first shot. The measured electron temperature profile in the core and the energy content are well predicted by the scaling law for χ. It is emphasized that the energy transport is not degraded when the density limit is approached. This behaviour is indicative of a hard density limit. The factor $H_{ITER89P}$ is slightly reduced to 1.4 because of a lower temperature pedestal. This is found to result from a decline of Δ to about 2 cm which is observed in ASDEX Upgrade discharges with higher line averaged densities.

References

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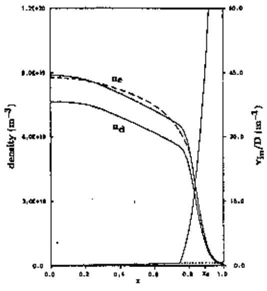

Fig.1. Profiles of electron density n_e measured by DCN interferometry and Li-beam diagnostic (dashed curve) and computed (solid curve), computed deuteron density n_d and corresponding v_{in}/D ratio. The normalized effective radius is denoted by x.

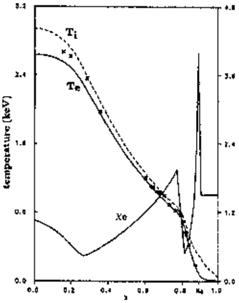

Fig.2. Profiles of electron temperature T_e measured by ECE diagnostic (crosses) and Thomson scattering (squares) and computed (solid curve), computed ion temperature T_i and electron heat diffusivity χ_e.

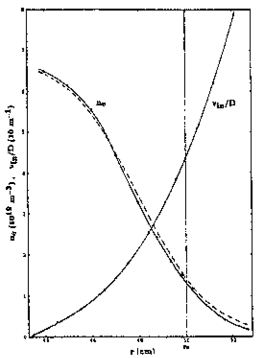

Fig.3. Profiles of measured (dashed curve) and computed (solid curve with dots) electron density and v_{in}/D ratio in the edge zone. The minor half-axis of a flux surface is denoted by r.

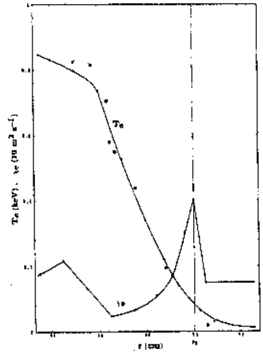

Fig.4. Profiles of measured (crosses and squares) and computed electron temperature and χ_e in the edge zone.