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Theoretical transport analysis in TJ-II scenarios with enhanced heat confinement

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Abstract

Experimental data show in a density scan performed in TJ-II that higher and higher central electron temperatures with steeper temperature gradients are obtained in TJ-II stellarator with the same heating power for decreasing values of density. The plasma pressure is increasing, showing an improvement of the confinement. These scenarios have been called enhanced heat confinement regime and resemble those plasmas that present electron neoclassical root. These plasmas are heated with ECRH and present flat or hollow density profile. The anomalous transport suppression due to strong central sheared electric field is studied using the predictive transport code PRETOR-stellarator. The results show that the phenomenon is compatible with a reduction of anomalous transport to neoclassical values and the onset of a positive radial electric field in the range 0<ρ<0.15 for these enhanced heat confinement shots. Nevertheless more studies are needed to be sure of this conclusion.

Experimental data

The data are collected from TJ-II stellarator [1]. Two discharges from a density scan are selected for these analyses. The first one, #2559, is a "standard" shot whereas the other one, #2562, is an enhanced heat confinement shot [2] (figure 1). The data used is the electron temperature and density measured by multi-point Thompson scattering profiles [3].

Anomalous transport model

The anomalous transport coefficient for the electron temperature is given by $\chi_a = C\chi_0/(1+f_E^2)$, where $\chi_0 = \varepsilon_t^{0.9}\left(c/\omega_{pe}\right)^2\omega_{bet}$, ω_{pe} is the electron plasma frequency, $\omega_{bet} = v_d/qR$ is the bounce frequency for toroidal ripple, v_d is the thermal velocity and C is a constant. The sheared electric field is introduced in the factor $(1+f_E^2)$, where $f_E = a\tau E_r^{'}/srB$ and $\tau = a\sqrt{\mu_0 m_i n}/B_p$. This model is quite similar to the current diffusive ballooning mode, although in this case no magnetic shear dependence factor has been added because TJ-II is an almost shearless device. The ion temperature profile is simulated with the Hinton-Hazeltine model with Chang-Hinton correction.

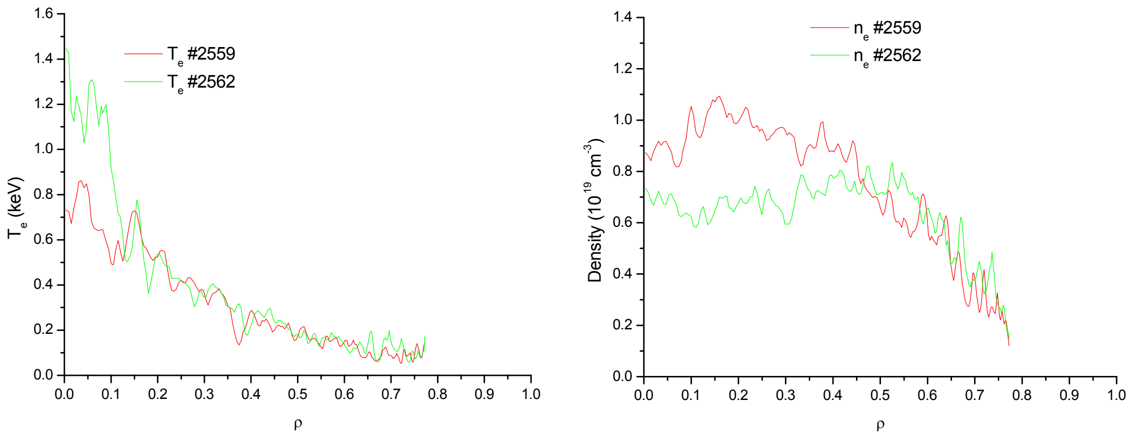

Figure 1. Electron temperature and density profiles collected from Thompson scattering in #2559 and #2562 shots.

Transport analysis

A complete transport study has been done using PRETOR-Stellarator [4] code. The electron density is fixed during simulation to fit experimental profile because enhanced heat confinement shots are very sensitive to density changes. The results of temperature simulation compared with experimental data are show in figure 2. The neoclassical electric field structure and its shear for both shots is shown in figure 3. As can be seen from the graphics, experimental temperatures are simulated with reasonable accuracy by this transport model. The electric field is calculated using the ambipolar condition, $\Gamma_e^{asym} = \sum_k Z_k \Gamma_k^{asym}$, where Γ_e^{asym} is the asymmetric part of the neoclassical electron flux, Γ_k^{asym} and Z_k are the asymmetric neoclassical ion flux and the ion charge for each species k respectively.

The neoclassical electric field has a high value, $E_r \approx 145V/cm$ at the plasma core for the #2562 shot and a small one, $E_r \approx 40V/cm$, for the standard shot #2559. In both shots it has a transition between electron and ion root around $\rho \approx 0.25$. The measured radial electric field in plasmas that present eITB is in the range of 100-150 V/cm, and without eITB is in the range 40-50 V/cm, hence the results obtained in this paper show good agreement with experimental ones [5]. The ambipolar equation has only one solution in the whole plasma range for this plasma configuration.

From figure 3 it can be seen that not just electric field is increased but $E \times B$ sheared flow appears in shot #2562. The maximum value is at the plasma center corresponding to #2562 shot, $dE_r/dr \approx 500$ kVm^{-2}, while for #2559 shot is $dE_r/dr \approx 180$ kVm^{-2}. For $\rho \approx 0.1$,

$dE_r/dr \approx 300$ kVm^{-2} in #2562 case and $dE_r/dr \approx 0$ kVm^{-2} in #2559 shot. These values are comparable to the fields obtained in similar ITB shots observed in tokamak experiments as well as in stellarators [6].

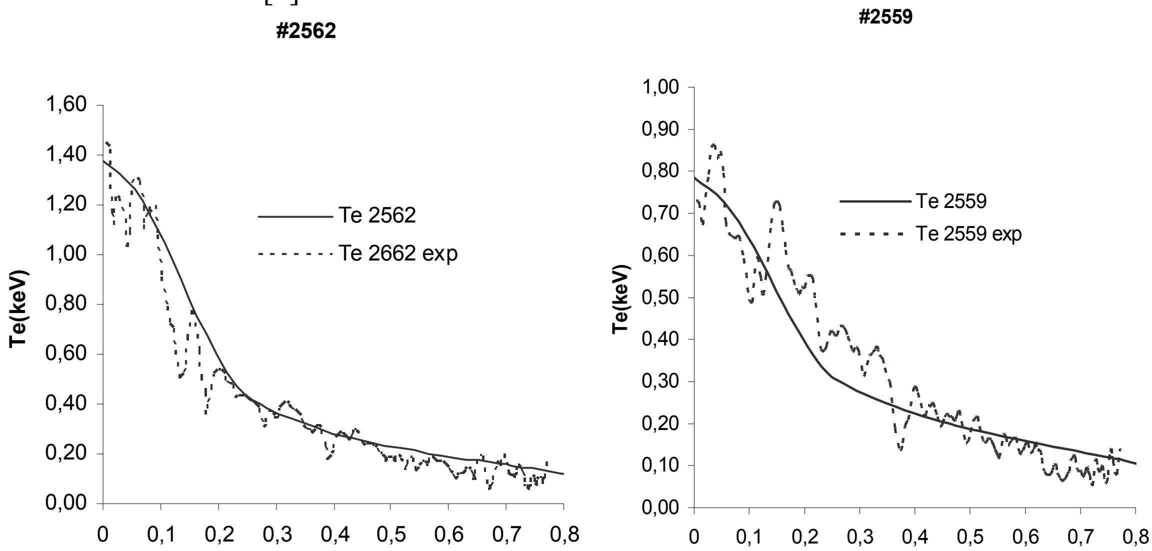

Figure 2. Electron temperature profile simulations of shots #2562 and #2559 made with the model previously described

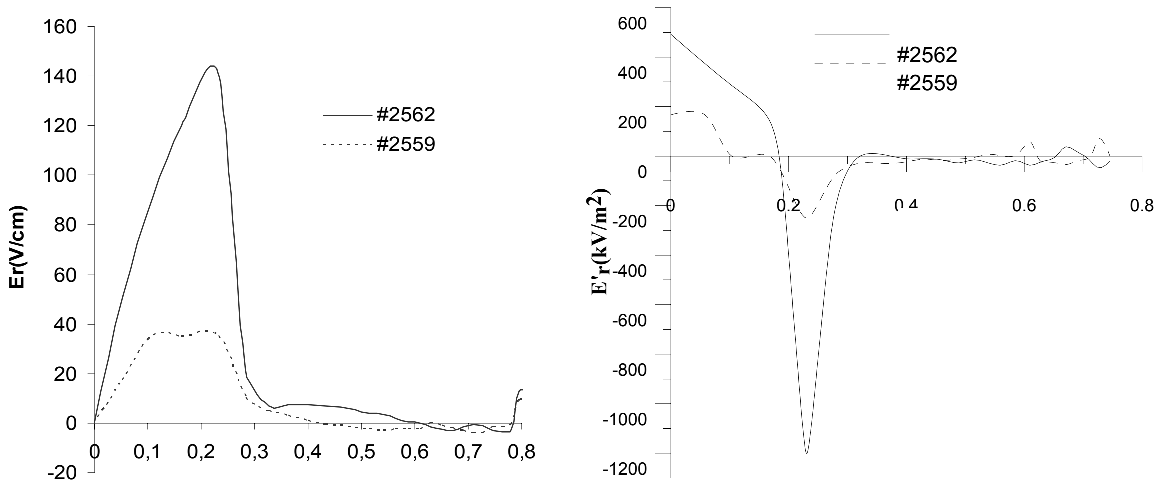

Figure 3. Calculated electric field profile in the case of #2559 and #2562 shots (left). Derivative E_r profile which gives $E \times B$ shear flow (right)

In order to see the transport reduction to neoclassical values a comparison of experimental diffusivity with the neoclassical one has been performed for every shot in the range $0 \le \rho \le 0.3$ in figure 4. It is clear from the figure that in #2562 shot those experimental and neoclassical values are comparable in the $0 \le \rho \le 0.2$ range. It can be deduced that comparable values of both profiles are obtained in $0 \le \rho < 0.1$ range for #2559 shot.

According to these data, it seems to be clear that there is an electron diffusivity reduction in plasma center to neoclassical values in the case of low-density scenarios. This reduction is localized in the plasma range where $dE_r/dr > 0$.

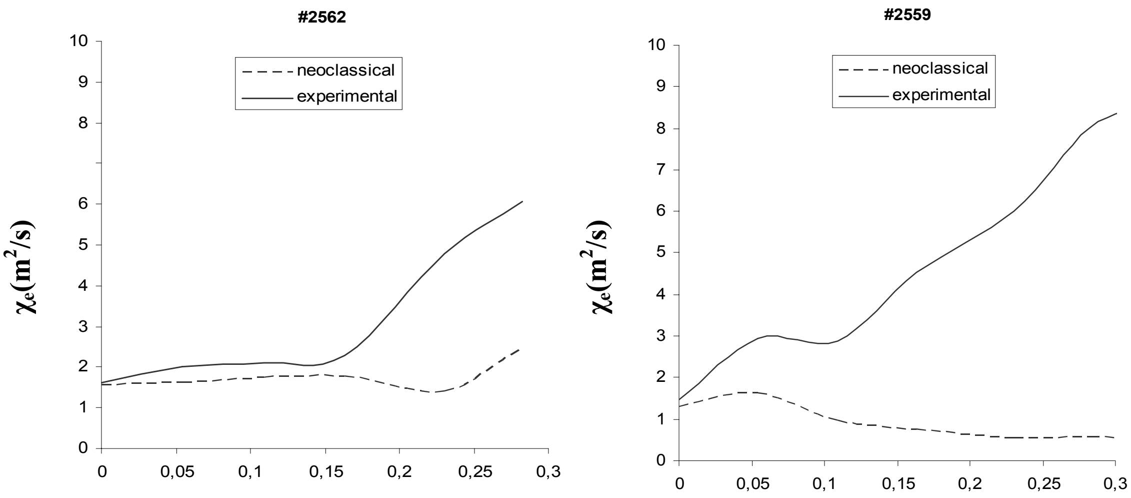

Figure 4. Comparison of anomalous and experimental electron diffusivities profiles at the plasma centre in #2562 shot (left) and #2559 shot (right)

Conclusions

A new transport model has been added to transport code PRETOR-Stellarator in order to analyze the transport properties of eITB shots in TJ-II. The main characteristic of this transport model is its strong dependence on radial derivative of electric field.

The results show that this transport model reproduces reasonably well the temperature profile of shots with ITB and without ITB. For both discharges the electric field obtained has a high value at the center and a small one close to the edge, but in the case of ITB, this central value is much higher, 145 V/cm, compared to 40 V/cm. These results are quite similar to the experimental data. Both, high electric field and high sheared electric field, are present when eITB is formed, although more studies have to be done in order to clarify what effect is more important for transport reduction.

The analysis of thermal diffusivities shows a reduction to neoclassical values at plasma center when eITB is formed.

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