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Benchmarking of electron heat diffusion models in TJ-II plasmas

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Abstract

PRETOR-Stellarator predictive transport code has been used to simulate transport phenomena in TJ-II. Some new electron heat diffusivity models have been introduced in the code in order to compare their results with the experimental ones in TJ-II and, hence, to elucidate their validity to explain TJ-II transport properties. Two types of discharges have been considered to perform the benchmarking of these models, the first one corresponding to a standard shot and the other one to enhanced heat confinement regime. Results show that semi local χ_e-scaling developed to explain W7-AS results show a good agreement with the experimental data. Regarding the drift-wave based model, we have to say that, although the included models were developed to simulate tokamak shots, a reasonable agreement with experimental data is obtained.

Introduction

We have developed the PRETOR-Stellarator transport code[1]. PRETOR code, that was developed initially to simulate tokamak shots, was completed in the “Departament de Física i Enginyeria Nuclear” of “Universitat Politècnica de Catalunya” DFEN with a new module capable to simulate stellarator shots. PRETOR-Stellarator is being used to simulate TJ-II shots.

TJ-II[2] is a medium size four periods stellarator, of flexible heliac type, with magnetic field $Bt_0 \leq 1.2$T, major radius R_0=1.5 m, average minor radius $\langle a \rangle \leq 0.2$ m, that can achieve a wide range of rotational transform values at the center: $0.9 \leq \iota(0)/2\pi \leq 2.2$.

Usually the LHD pseudo-experimental model[3] is used in transport study of TJ-II. In this paper new models are added in order to check the goodness of each one and make a comparison among them. The results could be interesting in order to improve the transport calculations in TJ-II or confirm the validity of the usual model used. Also the implementation of the theoretical transport models would help to enlarge the validity of these theories developed for tokamaks plasmas that have not been used in TJ-II plasmas.

Experimental data

The two discharges used from a density scan are plotted in figure 1. The first one, #2559, is a "standard" one whereas the other one, #2562, is an enhanced heat confinement shot[4]. The data used are the electron temperature and density measured by a multi-point Thompson scattering. The electron temperature is higher in shot #2562 with a high gradient at ρ≈0.1, for effective radius greater than 0.15 both temperatures profiles being almost the same. The plasma is composed of hydrogen and is heated with 300 kW of Electron Cyclotron Heating (ECH). The power deposition profile is assumed Gaussian in these simulations. Both discharges have different density profiles but the same absorbed and radiated powers.

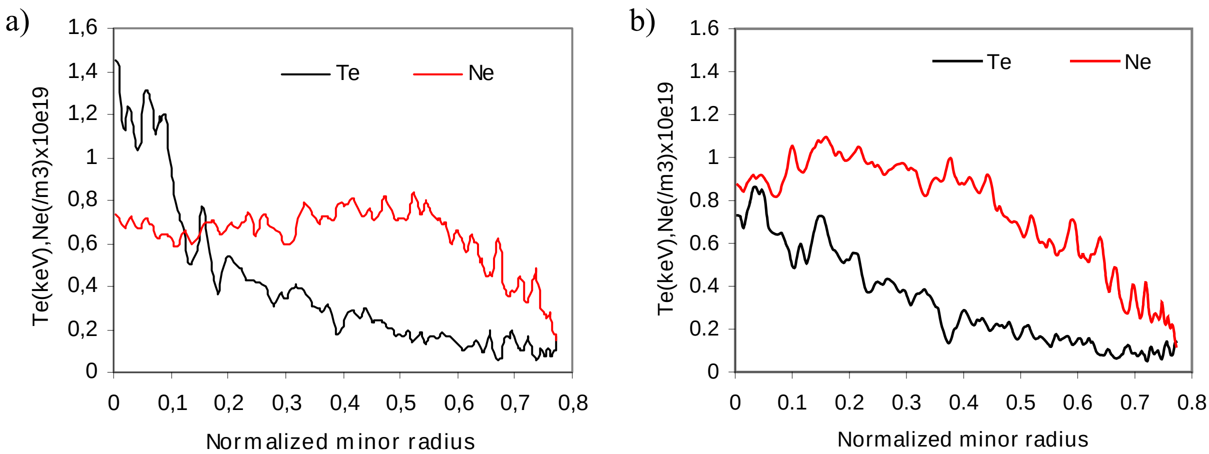

Figure 1. Electron temperature and density collected from Thompson scattering in #2562 (a) and #2559 (b) shots.

Models used for simulations

Three models have been introduced in PRETOR-Stellarator and used for simulations presented in this work:

- *LHD* Model[5]

In this case there are four parameters to adjust the thermal conductivity. One of them is fixed (*fimpre*), and it is used in order to adjust global confinement, the other three are adjustable with the parameters screen of PRETOR in order to obtain good agreement with electronic temperature profile.

$$\chi_e = 15.8 B_{T0}^{-2} R_0^{-0.4} n_e^{-0.26} T_e^{1.38} fimpre^{-2.38} \frac{1 + Ct1\rho^{Ct2}}{1 + Ct1 \cdot Ct3^{Ct2}}$$

T_e is expressed in keV, n_e in 10^{20} m^{-3} and the others in the usual units.

- W7-AS Model[6]

The model only has one parameter to fit the central temperature.

$$\chi_e = 0.64\left(\frac{R_0}{2}\right)^{-0.75} B_{T0}^{\ -0.6}\iota_0^{\ -0.49}P_{elec.}^{0.76}n_e^{\ -0.95}\ \frac{1}{Ct1}$$

In this case appears the rotational transform in the centre (ι_0) and the total power deposition $P_{elec.}$

- Theoretical electromagnetic drift wave model [5] (EM)

Although it is a theoretical model it has also two parameters to fit the experimental electron temperature profile. In this case the parameters serve to weight the importance of two types of transport, the toroidal and helicoidal trapped particle transport.

$$D_{EMt} = \varepsilon_t^{1/2}\left(\frac{c}{\omega_{pe}}\right)^2 \omega_{bet} \qquad D_{EMh} = \varepsilon_h^{1/2}\left(\frac{c}{\omega_{pe}}\right)^2 \omega_{beh}$$

$$D_{ANe} = Ct1 D_{EMt} + Ct2 D_{EMh} \qquad \chi_e = \frac{5}{2} D_{ANe}$$

Where ε_t and ε_h are the toroidal ripple and helical ripples, ω_{pe} is the electron plasma frequency; and the other two frequencies are the electron bounce frequency defined as:

$$\omega_{bet} = \varepsilon_t^{1/2} v_{the}\frac{\iota}{R_0} \qquad \omega_{beh} = \varepsilon_h^{1/2} v_{the}\frac{M}{R_0}$$

Where v_{the} is the electron thermal velocity; ι the rotational transform and M the number of periods of the device.

Results

Simulated temperatures are plotted in figure 2. In order to check the goodness of every model the next expression for the errors has been used $\sigma = \sqrt{\sum_i (T_i^{\exp} - T_i^{simul})^2} \Big/ \sqrt{\sum_i (T_i^{\exp})^2}$ and the results are presented in the table1. W7-AS model shows a good agreement with the experimental data for #2559 shot and the drift-wave based models, although derived for tokamaks plasmas, a reasonable agreement with experimental data is obtained for both kind of shots. Taking into account the fact that electromagnetic drift wave gives rise to a $v_{\|}\delta B/B$ diffusion, magnetic topology seems to play an important role in enhanced confinement shots.

Shot	EM	LHD model	W7-AS model
#2559	25%	29%	15%
#2562	28%	57%	40%

Table 1. Errors in the simulated temperature.

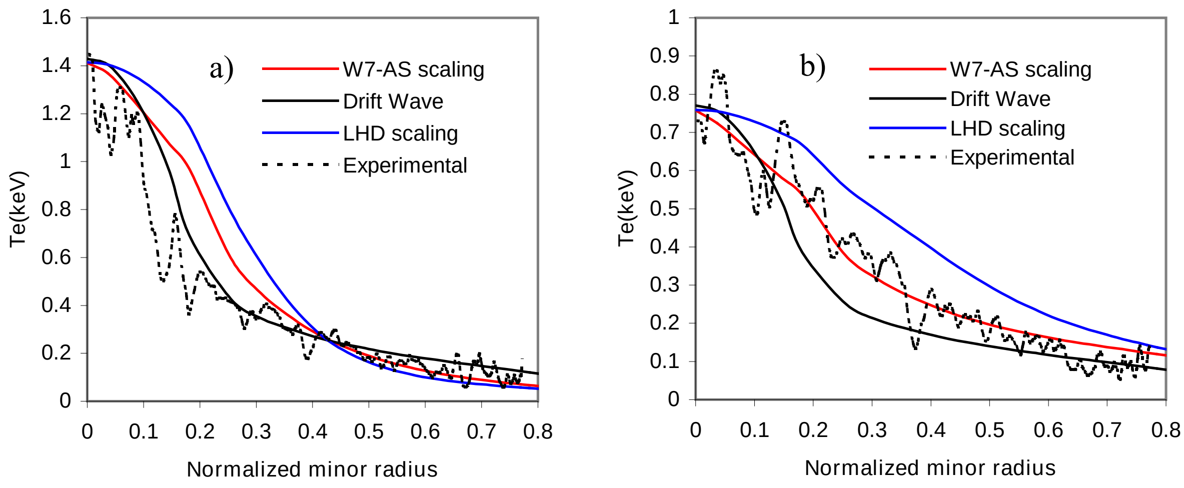

Fig.2 Experimental and simulated electron temperatures profiles for the enhanced heat confinement shot #2562 (2a) and the standard shot #2559 (2b)

Conclusions

In this paper some transport models are added to PRETOR-Stellarator and the simulated temperatures are compared with the experimental data. Two different types of discharges are simulated: a "standard" shot and another one with enhanced heat confinement.

It has been shown that the best model implemented in PRETOR-Stellarator to simulate "standard" discharges of TJ-II is W7-AS model. It is worth to point out that with only one free parameter and no explicitly minor radius dependence the W7-AS model fits with just σ=15% of average error the electron temperature. The goodness of W7-AS model could point to the similarity of transport properties of plasmas heated by EC-waves in stellarators.

Although the theoretical electromagnetic model was derived for tokamaks, it fits reasonably well with the experimental data in the case of "standard" shot. In the case of enhanced heat confinement, the experimental electron temperature profile is very similar to the calculated with drift waves. In this situation a possible explanation of the enhanced confinement scenarios is a reduction of the turbulence to drift waves values. But these results depend strongly on the simulation of the ripple and must be taken with some caution and further analysis of the theoretical electromagnetic model should be done in order to clarify the factors that make this model fits with accuracy the enhanced heat confinement scenarios.

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