Internal Heat Transport Barriers in TJ-II

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1.- INTRODUCTION

One of the main problems to reach the magnetic confinement fusion is to improve the transport properties of the devices. Several phenomena appear in the plasma under specific conditions that contribute to diminish the particle or energy transport. These phenomena allows to reach enhanced confinement regimes and to achieve the reactor conditions in tokamak and stellarators. The H mode and the Reversed Shear are examples of enhanced confinement scenarios. Other enhanced confinement regimes have been achieved through the formation of internal transport barriers that reduce the transport and, hence, improve the confinement.

2.- DESCRIPTION OF INTERNAL TRANSPORT BARRIERS IN TJ-II

In some TJ-II stellarator plasmas peaked temperature profilesand hollow density ones are present. These profile features appear when plasma starting and heating is performed using the line QTL2 ECRH launching line, at second harmonic of X mode. This line is characterised by a localised power deposition profile and high power density, being the injected power 300 kW. Measurements of electron temperature profile are performed using the 8 high-field-side ECE channels, and by Thomson scattering. Density profile is obtained at a single time by Thomson scattering and line density is measured using an interferometer. Both profiles are shown in figure 1. This kind of discharges is obtained when high power density is applied by ECRH and when the electron density is low. In this case the temperature profile presents a steep gradient near reff=0.05 m and the registered central temperature ranges typically between 1,5 and 2 keV. This high temperatures are also registered by Thomson Scattering system, which ensures that this effect is not due to the presence of superthermal electrons and responds to real energy increase of the bulk electron distribution function.

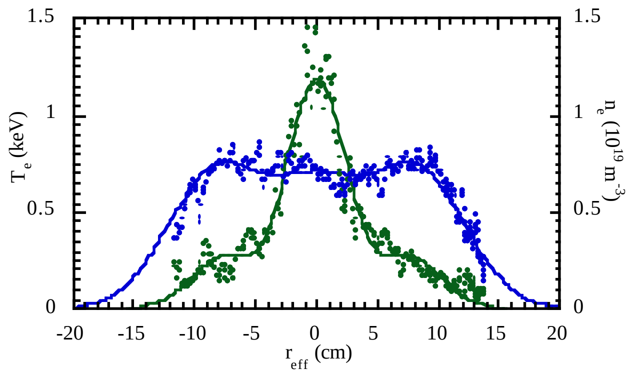

Figure 1.

The steep temperature gradient is a clear indication of an internal heat transport barrier (ITB), as will be demonstrated by transport analysis. Nevertheless, the energy content of in plasmas with ITB is not higher than the one in plasmas without ITB, since the volume where the temperature is higher is a small fraction of the total one, and, moreover, the hollow density tends to diminish the plasma kinetic energy. These plasmas are also characterised by an enhancement of the oscillations of the temperature registered by the ECE central channels and by some sudden transitions of the peaked temperature profile to a less pronounce temperature gradient. The typical time scale of these oscillations is of the order of 1 ms. These oscillations do not seem to propagate outwards the transport barrier or their typical propagation lengths are less than the distance between the 7th (inside the barrier) and 6th (outside the barrier) ECE channels. All these evidences point to the dynamic of the distribution function as an important ingredient to explain these phenomena.

3.- TRANSPORT ANALISYS

Proctr code[1] has been modified to perform transport analysis of these discharges. The transport barriers are introduced in the electron heat conductivity through the expression:

$$\chi(r) = \chi_s(r) \times \left[1 - h \exp\left(-(r - r_b)^2 / w^2\right)\right] \qquad (1)$$

Where h is the height of the barrier, r_b is the radial position, w is the width and χ_S is the smooth heat conductivity, obtained from transport analysis of discharges without barriers.

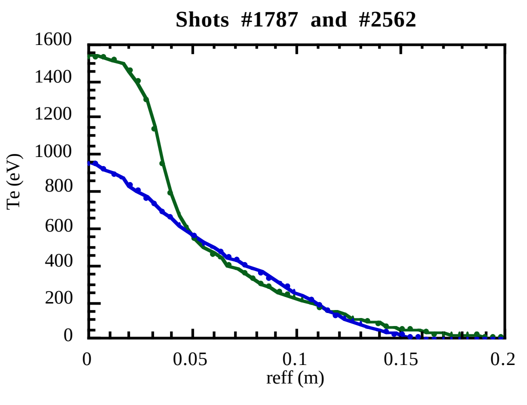

Figure 2

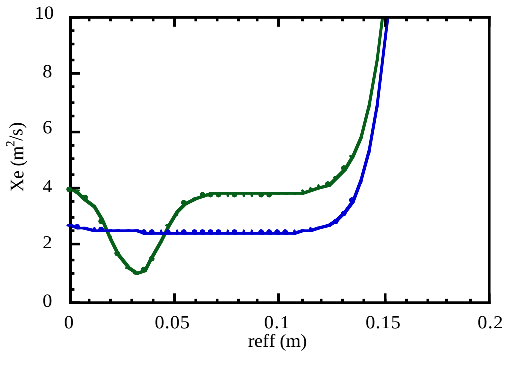

Figure 3

Assuming this conductivity shape, the simulation of the heat transport for those discharges that

[1] F. Castejón et al. "Transport evaluation in TJ-II plasmas", Paper presented at 12th International Stellarator Conference, Madison, Wisconsin, USA, 1999.

present such steep gradients has been carried out. The parameters of the conductivity are adjusted in such a way that the simulated temperature profile fits the experimental one. The barrier must be placed at the point of steepest temperature gradient. The temperature profile in plasmas with and without barrier are plotted in figure 2. The simulated conductivity as compared with the one coming from the transport analysis of a discharge without transport barrier is plotted in figure 3.

4.- THE PARTICLE TRANSPORT

ITBs are obtained in TJ-II in discharges with hollow density profiles. Therefore transport properties are only improved for the heat transport but not for the particle one, since no steep gradient of density appear at the barrier position.

The experimental density profile is hollow, maybe due to the pump-out effect of ECRH. In fact the hollowness would give an inward flux that should be able to compensate the outward flux provoked by EC wave absorption. It is observed that the more hollow the profile, the steeper the temperature gradient. It has been suggested that the improvement of heat transport is not accompanied by the enhancement of particle confinement because the non-diagonal terms of transport matrix are degraded. An hypotetic decreasing of particle diffusion would be compensated by the increasing of non-diagonal terms.

It is also observed that transport barriers are better established for low density discharges. This fact indicates that the crucial parameter for the barrier formation is the rate between the power density and the particle density.

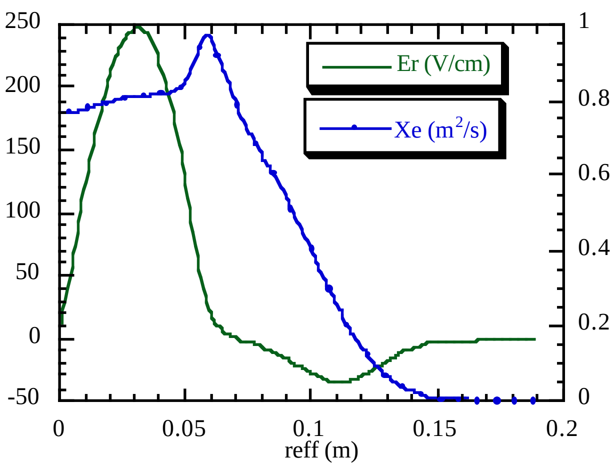

Figure 4.

5.- COMPARISSON WITH NEOCLASSICAL TRANSPORT

Neoclassical transport theory predicts that an electric field appears to keep the ambipolarity of particle flux: the higher mobility of the electrons causes the neoclassical electron flux to be larger than the ion one and an electric field appears that makes both fluxes equal. When the field is positive and large in the centre of the plasma it is said that the plasma is in the electron root, since the field tends to retain the electrons. In this case the transport coefficients are much less than those without field.

The electron root could be established in a stellarator when a high electron flux appears due to the fact that the EC waves push electrons to the ripple trapping region and these particles escape from the plasma. Then an ambipolar strong positive field that improves the transport is established.

The neoclassical electric field calculated with the MOCA code is plotted in figure 4. The neoclassical heat conductivity is also plotted in figure 4, where it is seen that is a factor 2 lower than the obtained using the modified Proctr code.

6.- THE POWER THRESHOLD

In the case that the crucial parameter is the power density over the particle density, for similar densities the power threshold will scale as the volume of the flux tube where the microwaves are absorbed, which is roughly proportional to major radius. Therefore, the power threshold should be 50 % higher in TJ-II than in CHS torsatron. The experiments performed in CHS shows a power threshold of 170 kW, which gives a threshold of about 250 kW in TJ-II. This result is i nagreement with the experiments performed in TJ-II in which the power threshold for the apparition of transport barriers is between 200 and 300 kW of injected power.

7.- CONCLUSIONS AND DISCUSSION

The electron confinement enhancement in the plasma core has been previously observed in W7-AS[2] and CHS[3] stellarators. This phenomenon is explained in neoclassical terms in W7-AS, considering that a strong ambipolar positive radial electric field, that reduces the outward electron heat flux, is created, i. e., the electron root appears in the plasma core and a transport barrier is not strictly created. CHS team claims that transport is reduced because an outward non-uniform radial electric field reduces the plasma turbulence and causes the transport barrier formation. A feasible explanation of the phenomenon could be the following: the ripple trapped electrons are pumped out by ECRH, since the diffusion in momentum space pushes particles into the loss cone. Because of the ambipolarity condition, an outwards electric field is created that is able to reduce both, neoclassical and anomalous transport. More studies are necessary to state how important is the anomalous transport or the effect can be explained using only neocalssical theory.

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[2] H. Maaβberg et al. Phys. of Plasmas **7** (2000) 295
[3] A. Fujisawa et al. Phys. Rev. Letters **82** (1999) 2669