Enhanced heat confinement in TJ-II heliac plasmas

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1. Introduction
TJ-II is a four periods, middle size stellarator with helical magnetic axis which plasmas are heated by two gyrotrons of 300 kW each. Enhanced Heat Confinement (EHC) discharges have been obtained in TJ-II low density plasmas when high power density is applied (typically 300 KW with QTL2). These shots are characterised by peaked temperature profiles and flat or even hollow density ones. Despite the low density, it is seen that the confinement is improved, since the plasma pressure is higher in this kind of discharges for the same heating power. These regimes are better obtained with hydrogen than with helium plasmas and when the limiter is inside the plasma. This latter experimental fact is due to the diminishing of the plasma-wall interaction.

The EHC regime has also been observed in W7-AS and CHS stellarators in similar conditions as TJ-II. The apparition of a strong positive electric field is predicted by neoclassical calculations in W7-AS using DKES code and in TJ-II using MOCA code, i.e., the plasma happens to be in the electron root regime. The existence of such positive electric field has been verified experimentally W7-AS using CXRE and in CHS using a HIBP, and a reduction of turbulence is observed near the maximum electric field shear.

2. Transport Evaluation.
Transport analysis of discharges that present EHC regime shows a reduction of electron heat conductivity. The neoclassical estimations for these TJ-II profiles show the apparition of a strong positive electric field that tends to reduce the electron thermal conductivity, i.e., the plasma is the electron root regime. Transport analysis of experimental data performed by the modified version of Proctr code show a strong reduction of heat conductivity in the TJ-II plasma core. The mechanism that can explain the generation of such a strong positive electric field is the existence of an enhanced outward electron flux due to ECH pump-out, then the ambipolar condition ensures the apparition of such a field to balance ion and electron fluxes. Nevertheless, the question on the importance of anomalous transport reduction for the confinement enhancement remains open.
3. Density Scan.

It is observed that EHC regime is better establish for high absorbed power density, \( w \), and for low particle density, \( n \). Therefore, the key parameter to establish the EHC regime is \( w/n \). Transport in TJ-II core is improved when this parameter is increased. The dependence of \( \text{grad}(T) \) and \( \chi \) on this parameter is seen to be non-linear, i.e., the key parameter is \( (w/n)^\alpha \). In this work a systematic density scan is presented to extract the dependence of heat conductivity on density and, hence, to evaluate the exponent \( \alpha \).

Figures 1a and 1b

Figures 1a and 1b show temperature and density profiles for this density scan. Figure 2 shows the electron heat diffusivities for these shots. It is seen that the core conductivity falls when density decreases. Figure 3 shows the dependence of maximum \( \text{grad}(T) \) and of average \( \langle \text{grad}(T) \rangle \) and central heat diffusivity \( \chi_0 \) on central density. Both quantities show a much stronger dependence than linear. In fact, \( \text{grad}(T) \approx 1/n^{-1.3} \), \( \langle \text{grad}(T) \rangle \approx 1/n^{-3.6} \) and \( \chi \approx 1/n^{5.5} \). It still remains extracting the dependence on power density. Moreover, \( w \) and \( n \) can depend one of another, which can explain the former strong dependencies.

Figure 2

Figure 3
4. Magnetic configuration Scan.

A magnetic configuration scan has been performed in TJ-II to investigate the behaviour of EHC regime. Only a first puffing at the beginning of the discharge in order to have low density. Figures 4a and 4b show temperature and density profiles corresponding to 4 different magnetic configurations. The vacuum ι profile is shown in Figure 5, where it can be seen that the 3/2 resonance almost appears in the centre of the plasma for 100_40_63 configuration and is moving outwards up to configuration 100_34_61. The actual position of this resonance can be clearly modified by the plasma5.

The shapes of profiles suggest that in the configurations 100_40_63 (shot 4077), 100_38_62 (shot 4081) and 100_36_62 (shot 4088), the resonance seems to affect an important part of the plasma, while in configuration 100_34_61 (shot 4093) the resonance is in the outer part.

![Figures 4a and 4b](image)

Thermal diffusivity for these discharges is plotted in Figure 6. Transport analysis shows a light dependence of thermal diffusivity on magnetic configuration in the three first cases (shots 4077, 4081, 4088), with some improvement when rational surface is placed outside the plasma in the vacuum configuration. A possible explanation is that the resonance makes worse the confinement, but it is not clear, since the change is very small and can be attributed to other factors as the modification of power deposition profile and the changes of plasma-wall interaction.

But everything changes in 100_34_61 (shot 4093) magnetic configuration. The central value of thermal diffusivity is increased, showing worse confinement in the plasma centre and the EHC zone is wider. The feasible explanation for these observations can be that in the first 3 configurations the discharges under study present a low interaction with the wall and the level of impurities is low. $Z_{eff}$ should be also low and, therefore, electron collisionality too. In the last discharge the plasma-wall interaction could be stronger with the subsequent changes in the confinement.
Nevertheless, this big difference is not observed in electron temperature and density profiles when a 2nd gas puffing is applied to the plasma. This second puffing is able to increase the density and plasma current is also modified, which reinforces the hypothesis that the presence of the plasma is able to change the magnetic configuration.

5. Conclusions.
A strong dependence on density has been observed in EHC regime. The smaller the central density, the steeper the temperature gradient is. This dependence is in qualitative agreement with neoclassical calculations that predict the apparition of electron root in this long mean free path regime. The lowering of the density is favoured by the pump-out effect of EC-waves that creates an enhanced outward electron flux. The electric field, that appears to keep the ambipolarity condition, is able to reduce both neoclassical and anomalous transport, but the important of this last one must be addressed.

A magnetic configuration scan has been performed in TJ-II to explore the dependence of EHC regime on configuration properties. The shapes of electron density and temperature profiles change along the scan and so do transport properties. The change of the shape is a clear indication that the resonance is moving outwards the plasma along the scan.

The strongest modification of transport properties could be due to the modification of plasma-wall interaction due to the presence or absence of the resonance in the outer plasma radius.

6. References.

1 F. Castejón et al. Submitted to Nuclear Fusion for Publication.
5 T. Estrada et al. Oral presentation at this conference.