TURBULENCE DRIVEN CARBON IMPURITY TRANSPORT IN TOKAMAK PLASMAS

I. Voitsekhovitch, S. Benkadda, P. Beyer, M. Koubiti, Y. Marandet,
L. Mouret-Godbert, R. Stamm
PIIM, Université de Provence, France

G. Bateman, A. Kritz, A. Pankin
Lehigh University, Department of Physics, Pennsylvania, USA

I. Introduction

The knowledge of physical mechanisms of particle transport is a necessary step towards the control of plasma density in experimental tokamak scenarios. Predictive simulations of density evolution using the theory-based models is a tool to show the relevance of the model underlying physics to experiment. In this work we present the modeling of the main ion and carbon (C) impurity transport performed with the Multi-Mode Model (MMM) which is based on the quasilinear estimation of turbulent fluxes driven by different instabilities [1]. As an example, we apply this model to the RF heated discharges of Tore Supra, namely, to the lower hybrid current drive (LHCD) scenarios with current profile shaping [2, 3] and to the discharge with fast wave electron heating (FWEH) and ion cyclotron resonance heating (ICRH). The data for the modeling of the LHCD scenarios are taken from Refs. 2 and 3. Following Ref. 4 we use the data for the FWEH and ICRH discharge 19542 from the ITER Profile Database [5] and we compare them with the data from Ref. 4.

The particular accent of this paper is the intrinsic C impurity transport and the influence of the C concentration on the scenario of the discharge. First, we present experimental scenarios and show the results of the modeling of energy and particle transport with the MMM model. Then, the influence of the influx of atomic C from the plasma boundary on the evolution of the discharge is studied in predictive modeling.

II. Experimental scenarios and modeling

Figures 1 and 2 show the experimental scenarios of the discharges chosen for our modeling. The LHCD scenario has been performed at zero loop voltage and full non-inductive current drive in a low density Helium (He) plasma. The formation of a core region with improved thermal electron confinement following the reversal of the q-profile (Fig. 3, right) (so called hot core lower hybrid enhanced performance (LHEP) transition) has been observed in this scenario. A second scenario presents the FWEH and ICRH heating in the He plasma with higher density. The detailed description of these discharges is given in Refs. 2-4.

The self-consistent modeling of thermal (electron and ion) and particle (main ions and C impurity) transport and current profile diffusion for these scenarios has been performed with an imposed RF power deposition profile and RF current density profile and prescribed influxes of atomic He and C and boundary conditions. The radial profile of particle source is calculated taking into account the atomic processes at the plasma edge. The simulations have been performed using the 1.5D transport code BALDUR.

In the experiments described above the control of the central line- averaged density through its feedback with the gas puffing prevents large variations of the density profile.
during the RF heating phase. The modeling of typical density profiles during the LHCD, FWEH and ICRH phases is shown in Figs. 3 and 4.

The combination of transport coefficients used in these simulations includes the resistive ballooning modes (RBM) driven transport dominant at the plasma edge, ITG turbulence and TEM driven transport in the gradient region and on-axis transport driven by kinetic ballooning modes (KBM) (Fig. 5). Our modeling shows that the ITG turbulence and TEM are linearly stable in the plasma core ($r/a \leq 0.2$) both in LHCD and FWEH/ICRH scenario. The particle transport in the later case is dominated by the RBM in large plasma region ($r/a>0.4$) with a small contribution from the ITG turbulence and TEM around $r/a=0.8$ (Fig.
while these instabilities provide much stronger contribution to the turbulent fluxes in the LHCD scenario (Fig. 5, left).

Fig. 5. The additive terms constituting the effective ion diffusivity in the MMM model used in the simulations of LHCD (left) and FWEH/ICRH (right) discharges.

### III. Influence of carbon impurity on experimental scenario

The influx of atomic C is a free parameter of our modeling which varies in experiments depending on the wall conditions. In the simulations above the value of C influx has been adjusted to reproduce the evolution of average value of $Z_{\text{eff}}$ determined from the bremsstrahlung radiation. The calculated profiles of C impurity for LHCD and FWEH/ICRH discharge are shown in Fig. 6.

Fig. 6. Calculated profiles of carbon impurity in the LHCD and FWEH/ICRH scenarios

The variation of the C concentration strongly affects the LHCD scenario. The increase of the C influx produces the increase of the density, $Z_{\text{eff}}$ and radiative power as well as the change of the growth rate for the ITG turbulence. As a result, the electron temperature reduces that affects the q-profile evolution. This effect is illustrated in Fig. 7. In contrast to the LHCD discharges, the variation of C influx from the plasma edge in the FWEH/ICRH scenario within the same range does not produce an important effect on the plasma density and temperature.
Fig. 7. Calculated plasma profiles at 8.5 s obtained with different carbon influx from plasma edge, \( \Gamma_C \). Experimental profiles are shown by dashed curves.

**IV. Summary**

This work presents the results of the modeling of the LHCD and FWEH/ICRH scenarios with the MMM model and shows the influence of the C concentration on the discharge evolution. We found that the combination of the theory-based models which includes the transport fluxes driven by the RBM, ITG turbulence/TEM and KBM gives a good agreement between calculated and experimental density profiles both for low density and high density plasmas. It has been shown that the contribution from the ITG turbulence and TEM to the anomalous particle flux is rather weak in the FWEH/ICRH discharge while these instabilities are more important for the LHCD scenario. The variation of the C concentration within factor 10 weakly affects the FWEH/ICRH scenario whereas it leads to a large changes of plasma profiles in the LHCD scenario. The analysis of C transport performed in this paper is a first step to a subsequent combined experimental and numerical study of impurity transport on Tore Supra and its impact on the evolution of the discharge.

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