THE IMPURITY BEHAVIORS AND TRANSPORT ANALYSIS OF HL-2A AND HL-3 PLASMAS

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1. MAIN TEXT FORMAT

Impurities can play a crucial role in fusion plasma performance through radiation losses and dilution of fuel in the plasma core [1]. It is therefore important to understand the impurity behaviors and their transport in the plasmas. Impurity transport is elucidated by the combined collisional and anomalous transport [2]. The collisional fluxes include three contributions which are the classical contribution arising from the perpendicular forces, the Pfirsch-Schluter contribution caused by the parallel friction in the short mean free path regime, and the neoclassical contribution in the long mean free path regime. Usually the Pfirsch-Schluter contribution dominates the interaction of heavy impurities with the protons, while neoclassical contribution is of importance in the case of high temperatures, low densities and low-Z impurities. For the helium, because of its small charge and low mass, helium under reactor condition will be in the banana regime together with the background ions (deuterium and tritium). A diffusion coefficient *D* and inward drift *V* is suitable to describe the anomalous transport.

The impurity densities and effective ion charge Z_{eff} have been extensively measured with spectroscopic techniques in the ohmic, L- and H-mode plasmas on HL-2A and HL-3 tokamaks. In the HL-2A plasmas, the poloidal asymmetry distribution of impurity sources is observed. Impurities released from the baffle and caused by plasma-baffle interaction flux into the plasma edge, yielding the local impurity accumulation towards the plasma boundary due to the impurity screening effect. The local impurity accumulation at plasma edge is accompanied by strong line radiations from the exited atoms and ions, which results in a local energy loss at the plasma edge and correspondingly a relatively-low temperature region is formed. In this region the recombination radiation and/or diatomic molecular band pseudocontinuum emission are increased and make an edge bulge in the measured bremsstrahlung profiles consequently. The sequential ionization events and diffusion results in an obvious Z_{eff} increase during auxiliary heating discharges. These observations also indicate that the desorbed impurity source due to plasma-wall interaction is localized and that the resulting particle influx has no time to spread out uniformly over the magnetic surfaces before a fairly high ionization state is reached. A similar phenomenon is observed in the HL-3 plasmas. The interactions between the plasma edge and puffed boron powders (in order to the wall condition improvement), during which the boron concentration and glow in plasma edge probably by the impurity screening mechanism and the simultaneous radiation (mainly the bremsstrahlung) enhancement in plasma center because of the impurity pollution occurs, are observed. Actually, a high confinement regime is achieved by the boron powder injection.

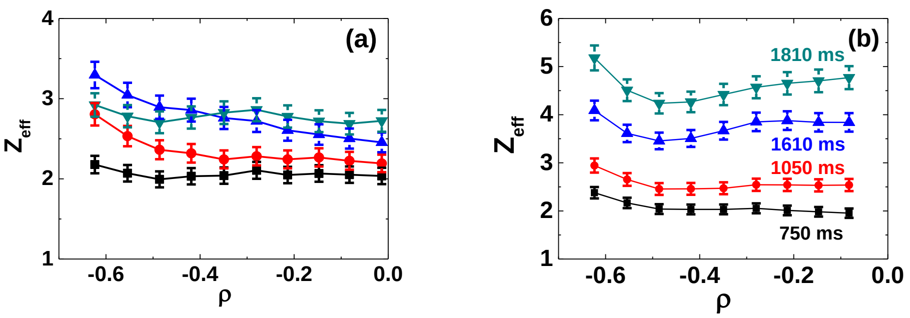

Fig. 1 Z_{eff} profiles during *L*- and *H*-mode phases in (a) Shot 31572 and during *L*-mode phases in (b) Shot 31580.

In the HL-2A plasmas, no center-peaked Z_{eff} profiles, i.e. the flat or weakly hollow profiles, emerge in plasma region of $-0.7 < \rho < 0$ in both L- and H-mode phases, as shown in Fig. 1(a), when the plasma has a low impurity level of $Z_{eff}(0) < 3$. The flat Z_{eff} profile indicates anomalous transport is prevailing. As $Z_{eff}(0)$ exceeds some threshold, i.e., $Z_{eff}(0) > 3$, Z_{eff} profiles tend to be center-peaked, as shown in Fig. 1(b). This is consistent with the neoclassical transport theory that strong inward convection of impurities can be expected when dilution of the main ion density is large and impurity-impurity driven terms in the transport cannot be ignored [3]. In this case as shown in Fig. 1(b), after the ECRH power is switched on, the $Z_{eff}(0)$ increases continuously, with Z_{eff} profiles tending to be peaked as indicated by the profiles at 1610 and 1810 ms. A considerable inflow of metallic impurities must contribute to such high Z_{eff} value. Note that all the unplotted Z_{eff} profiles from 1500 to 1800 ms follow the profile shape at 1610 ms, only with the profile amplitudes increasing gradually. It can be inferred that the collisionally induced accumulation may play a role on the impurity transport. The phenomenon that Z_{eff} maintains the profile shapes from 1500 to 1800 ms rather than keeping the peaking steadily increasing (i.e., the profile shape changes to be steeper) as the profile amplitudes increase indicates the collisionally induced impurity accumulation is seen to be weakened by an anomalous transport. Certainly, the radial diffusion coefficient D(r) and convective velocity V(r) need to be calculated by a transport code and compared to the neoclassical transport coefficients.

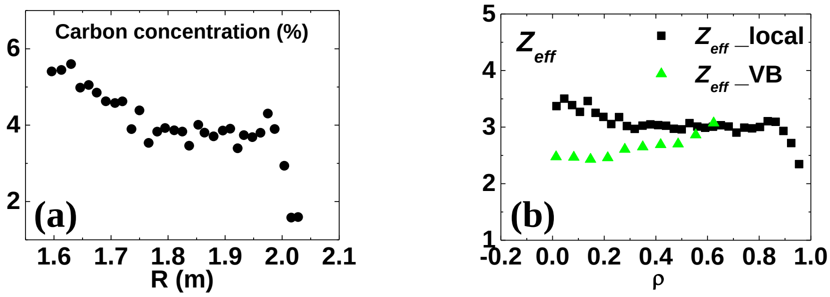

Fig. 2 (a) carbon ion concentration profiles measured by the CXRS diagnostic, and (b) Z_{eff} profiles calculated from local impurity concentrations (black squares) and visible bremsstrahlung (greentriangles) respectively.

The profile of absolute carbon ion density is calculated based on the charge exchange recombination spectroscopy (CXRS) diagnostic on HL-2A tokamak. Compared with the helium measurement, the carbon measurements are much less prone to the effects of ion plume emission. For the profile of carbon ion concentration as shown in Fig. 2(a), it is nearly flat at $\rho > 0.5$ region and the concentration is $\sim$ 4%, while it embodies an impurity accumulation at plasma core within the internal transport barrier (ITB) region which indicates the collisionally induced carbon accumulation. The carbon density profile is peaked compared to the electron density profile in the ITB. This is despite the fueling of electrons in the central region of the plasma from neutral beams and indicates that the carbon transport must differ from the electron transport. Also, because the C^{6+} profile is peaked on axis in the source-free region, inward impurity convection must play an important role in the transport process. Z_{eff} measured by the visible bremsstrahlung is shown in Fig. 2(b) with a slightly hollow profile. This suggests an interpretation in terms of multi-species interaction in such a manner that the lighter elements tend to expel the heavier ones from the central region. Hence, with relatively high concentrations of carbon only carbon will accumulate.
The high resolution imaging capability in HL-3 tokamak leads to advances in the characterization of ELMs along with their impact on PFCs. During type-I ELMs, main luminosity is on the lower divertor and upper baffle, indicating the enhanced particle recycling during the ELM pulse energy deposition. Nonetheless, Z_{eff} during one ELM event is decreased, indicating the impurites are expelled by the type-I ELMs.

ACKNOWLEDGEMENTS

This work was supported in part by the National Natural Science Foundation of China (Nos. 12275070), in part by the National Key Research and Development Program of China (Nos. 2022YFE03180200, and 2022YFE03020001).

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