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Studies on Ar and Kr impurity transport in KSTAR plasmas

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Impurities give detrimental effects on high-performance tokamak operations by diluting main fuel ions and causing significant radiation cooling, especially in the plasma core via line and continuum radiation. Meanwhile, well-controlled injection of gas impurities such as Ar near the divertor can help spreading out heat flux from plasma core to plasma facing components. Therefore, controlling not only intrinsic impurities such as tungsten but also gas impurities, such as argon and krypton, for the radiative mantle is an important and critical issue for International Thermonuclear Experimental Reactor (ITER) and future fusion reactors. The previous investigations by utilizing auxiliary heating such as electron cyclotron resonance heating (ECH) or ion cyclotron resonance heating (ICRH) have observed reduction in the core accumulation of impurities with enhanced transport, producing hollow impurity profiles at the plasma core. On the theoretical side, neoclassical transport theories are yet to explain many experimental results regarding impurity transport. There have been the recent progresses in exploring possible mechanisms for turbulence-driven impurity transports. Here, we provide the first measurements and analysis of argon and krypton impurity transport in Korea Superconducting Tokamak Advanced Research (KSTAR)

Experiments were conducted in KSTAR plasmas by injecting a trace amount of Ar gas as a test particle while applying ECH to investigate the effect of ECH on impurity accumulation inside the plasma [1, 2]. For L-mode plasmas, 350 kW, 110 GHz ECH was applied and the heating positions were varied at $r/a = 0$, 0.16, 0.30, 0.59 in the vertical direction by tilting the launching mirror. The argon radiation emissivity was measured by the two array 32 channel soft X-ray array diagnostics with Ar Ross filters. A significant reduction in the core impurity emissivity was observed with ECH. The reduction is the largest with the on-axis heating and becomes smaller with outward heating positions. The Ar particle diffusivity and pinch velocity were deduced by the ADAS-SANCO impurity transport code. In the plasma core ($r/a < 0.3$), the convection changes its direction from radially inward to outward with ECH, which is consistent with the observed reduction in the Ar accumulation. Neoclassical calculation by NCLASS and linear gyrokinetic simulation by GENE have been done, demonstrating that the Ar impurity transport is anomalous and neoclassical impurity transport fails to accommodate the observed convection reversal. From the GENE calculation, parallel compression pinch by trapped electron mode (TEM) enhanced by ECH may be responsible for the reversal of the convection velocities, even though it needs further confirmation. In addition, H-mode plasmas was heated by 170 GHz ECH with with fixed major radial position of R = 1.66 m and scanned its power from 0 to 800 kW. The emissivity of the Ar^{16+} and Ar^{15+} spectral lines were measured by the X-ray imaging crystal spectroscopy (XICS) and vacuum UV (VUV) spectrometer, respectively. The peak emissivity of Ar^{15+} was reduced by ECH, an effect largest with 800 kW compared to 600 kW of ECH. The Ar^{16+} emission increased with higher heating power. It was found that the inward convective velocity found in the plasma core without ECH was decreased with the ECH, while diffusion remained approximately constant resulting in a less-peaked Ar density profile. Theoretical results from the NEO code suggest that neoclassical transport is not responsible for the change in transport, while the microstability analysis using GKW suggests a dominant ion temperature gradient (ITG) mode during both ECH and non-ECH plasmas. For Kr, experiments injecting Kr gas from the divertor were conducted in H-mode discharges. ECH was also applied to control the core Kr impurity accumulation during Kr seeding. Amount of injected Kr was varied by scanning voltage of Piezo valve and its opening time. ELM crashes were suppressed by intermediate level of Kr seeding (3 V 25 ms) with slight degradation of electron density, core temperature and stored energy, while there was no effect on ELMs for low level of Kr (2 V 25 ms) and longer suppression and disruption for high level of Kr (3 V 50 ms). It is noted that stable suppression of ELM without a disruption was archived for ECH applied case with high level of Kr (3V 50 ms) and core electron temperature was not degraded significantly. Analysis results by SANCO impurity transport code will be presented to provide Kr transport, density distribution in the core under various injection conditions and to understand the role of ECH on Kr transport and its core accumulation.

References

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