Effects of α particles on plasma confinement and the removal of helium ash in the burning plasmas

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We have firstly studied effects of alpha (α) particles on CTEM- ZF system [1, 2]. Firstly, the dispersion relationship with α particles has been derived based on the linear gyrokinetic and bounce kinetic theories, and it is thus found that the density gradient driven CTEM instability in long wavelength regime can be destabilized by α particles mainly due to the downshift of real frequency by dilution effects, as compared to the case without α particles. This is essentially attributed to more precession resonant electrons around smaller phase velocity of CTEM and the consequent stronger excitation of CTEM instability. Besides, through the combination of α particles' effects on CTEM instability and polarization shielding, it is finally found that α particles can enhance the ZF growth rate driven by CTEM turbulence, and also broaden the range of radial wavenumber of ZF for positive ZF growth rate. This is mainly resulted from the destabilization of CTEM instability as well as the reduction of polarization shielding by the presence of α particles.

Meanwhile, effects of α particles on the transport of helium ash driven by CTEM turbulence are also analytically studied using quasi-linear theory [3]. It is found that the ratio between helium ash diffusivity and effective electron thermal conductivity $D_{\mathrm{He}}/\chi_{eff}$ driven by CTEM turbulence, which is a proper normalized parameter for quantifying the efficiency of helium ash removal, is smaller than unity. This indicates the less efficient removal of helium ash through CTEM turbulence as compared with ion temperature gradient (ITG) turbulence in [4]. However, the efficiency of helium ash removal is increased 55% by the presence of 3% α particles with their density gradient being twice that of electrons, and this enhancement can be further strengthened by steeper profile of α particles. This is mainly because the enhancement of helium ash diffusivity by α particles is stronger than that of the effective electron thermal conductivity. Besides, Increasing the fraction of T ions as well as the temperature ratio and flattening the density profile of electrons as shown in Figs. 1 and 2, are also beneficial to the removal of helium ash, and α particles further enhance the efficiency of helium ash removal under these favorable parameter regimes.

All these theoretical results are toward to provide the possible reference for improving the plasma confinement and expelling helium ash in the future reactors such as ITER.

References

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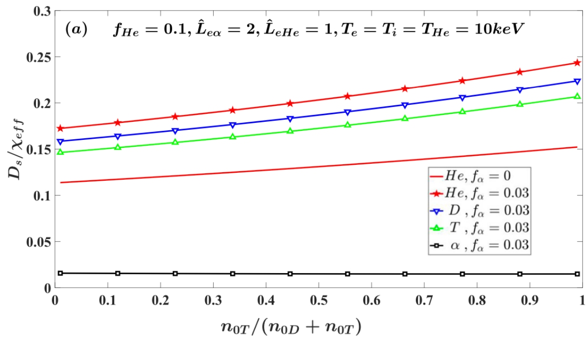

Fig. 1. Normalized diffusivity D_s/χ_{eff} of helium ash, D–T ions and α particles as a function of T ions.

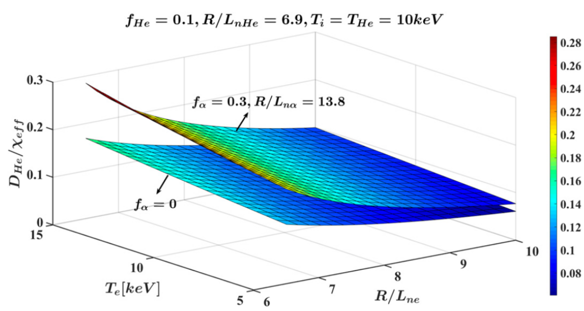

Fig. 2. Normalized diffusivity of helium ash $D_{\mathrm{He}}/\chi_{\mathrm{eff}}$ as functions of T_e ($T_i = T_{\mathrm{He}}$ = 10 keV is fixed) and R/L_{ne}