Gyrokinetic modeling of carbon density peaking in DIII-D tokamak

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This work presents quantitative comparisons between measured carbon peaking in a database of 134 DIII-D H-mode discharges and gyrokinetic simulations with CGYRO model [1]. A significant correlation of carbon peaking with ion temperature gradient, electron density gradient, and collisionality, major parameters determining real mode frequency, indicating an essential rote of ω_r in the carbon peaking. This observation is supported by a multilinear regression analysis, identifying ω_r and parallel compressibility $k_{\|}^2 = (\hat{s}/qR)^2$ as the most important parameters, explaining 93% of non-random variability in the measured carbon gradients. Investigation of the difference between the CGYRO model and measured carbon gradient reveals a significant discrepancy in ion temperature gradient (ITG) dominated discharges. Experimental values of R/L_{nC} in ITG are on average by 1.2 lower than from the model. Linear regression coefficients of the CGYRO model matched the experimental regression coefficient for ω_r, but the model regression coefficient for $k_{\|}^2 = (\hat{s}/qR)^2$ was three times lower. Previous studies of light impurity peaking at ASDEX Upgrade [2,3] and JET [4] suggested a non-negligible role of a roto-diffusion, diminishing the discrepancy for ITG dominated plasmas. However, strong correlations in the investigated databases did not allow for a clear experimental separation of temperature and rotation contribution to the carbon convection. A counter-current neutral beam injection available on DIII-D enables dedicated rotation scans with other plasma parameters nearly fixed. The role of the roto-diffusion was thoroughly investigated in several rotation scans demonstrating a near-zero roto-diffusion in TEM, weak ITG, and strong ITG dominated cases. TEM and weak ITG cases agree with CGYRO, but the significant increase of outward rotodiffusion predicted in strong ITG cases was not observed. Finally, we have compared the database with nonlinear ion scale CGYRO runs, and gyrofluid TGLF runs. While quasilinear runs remarkably well reproduce the nonlinear runs, a discrepancy is found for TGLF thermodiffusion, which is only a half of CGYRO value in strong ITG cases. As a result, TGLF systematically overestimates carbon peaking compared to CGYRO, which is already too high with respect to the experiment.

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