Neoclassical impurity transport in full-f global GYSELA simulations

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Impurities are present in tokamak plasmas due to three components: wall erosion (mainly from ELM events), gas injection and products of fusion reactions. Impurity accumulation in the plasma core can be detrimental. Fusion reactions can be unreachable due to plasma dilution [1] and the cooling effect of radiations can lead, in the worst case, to disruptive events by radiative collapse [2]. These events put an upper limit to the impurity concentration for ITER. In magnetized plasmas, impurity fluxes result from the competitions between diffusion and convection due to density gradients, temperature gradients and velocity gradients [3,4]. Complex impurity transport mechanisms take place from the multi-gradients profiles and strongly dependend on impurity mass A and charged Z numbers. Two phenomena usually coexist and play a role in the impurity dynamics, both having their own multi-gradients dependency: turbulent and neoclassical transport. Neoclassical transport is governed by the plasma collisionality parameter $\nu^{\star}$.

Most numerical studies investigate impurity transport using two separate codes, one for neoclassical dynamics, one for turbulent dynamics. It is desirable to consider neoclassical and turbulent impurity transport in a unique framework in order to emphasize possible synergies. The appropriate tool is a gyrokinetic code because the considered plasmas are weakly collisional. The aim of the present work is to recover the well-known neoclassical results for impurities by means of global and flux-driven gyrokinetic simulations.

The simulations are performed in the flux-driven regime with the GYSELA (GYrokinetic SEmi-LAgrangian) code [5]. This global code solves the gyrokinetic equations for the full ion and impurity gyro-center distribution functions, coupled to the quasi-neutrality equation. The code accounts for inter-species energy and momentum exchanges. The case of purely neoclassical transport is first considered by keeping the temperature gradients below the ITG instability threshold. The collisionality of interest for the main ions (Deuterium) is scanned ($\nu^{\star} \in [0.02 \rightarrow 2]$) investigating impurity transport in banana and plateau regime. All three constitutive terms of impurity neoclassical transport: diffusive coefficient D, pinch velocity $V_{\nabla n_i}$and thermal screening factor H; are reviewed by means of three distinct kinds of simulations. Starting with flat Deuterium density and temperature ($T_i = T_z$) profiles, the impurity density gradient is scanned in order to determine the diffusion coefficient. In a second stage, the finite Deuterium density gradient cases allow to probe the impurity accumulation process. The third set of simulations operate with a finite temperature gradient, in order to calculate the thermal screening factor.

This procedure has been carried out for a broad range of impurity charge numbers ($Z \in [2 \rightarrow 18]$). Numerical values compare fairly well with the analytical neoclassical calculations [6], within 10%. Simulations in turbulent regime are run for trace impurity ($n_z \sim 10^{-3} n_i$). Possible synergistic effects between neoclassical and turbulent transport will be particularly investigated (as turbulent corrugations of temperature and density which change localy the neoclassical transport).

References:

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