24P037-P

Development of coupled IMPGYRO-SOLPS codes for analyzing tokamak plasmas with tungsten impurities

タングステン不純物を含むトカマクプラズマを解析するための結合コードIMPGYRO-SOLPSの開発

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For the purpose of a consistent treatment of tungsten impurity together with background plasma, coupling of the IMPGYRO and SOLPS codes has been undertaken. The fluid part of SOLPS transfers the background plasma data to the IMPGYRO kinetic code, while IMPGYRO transfers the effect of tungsten impurities to SOLPS. An initial test calculation has been performed under a simple model for the impurity generation. The initial impurity generation results in a relatively large radiation loss and plasma cooling. The resultant suppression of further impurity generation leads to the quasi-steady state in the coupled calculation.

1. Introduction

A numerical simulation code IMPGYRO is being developed for kinetic treatment of high-Z impurities, such as tungsten. The main features of IMPGYRO are as follows: 1) The code solves exactly the equation of motion for each impurity particle for a given magnetic field configuration and background plasma without any guiding center approximation, 2) Coulomb collisions with background deuterons are included by the binary collision method, 3) Multi-step ionization and recombination processes are simulated, and 4) IMPGYRO has been coupled to the EDDY (Erosion and Deposition based on the DYnamic method) code [1] to evaluate sputtering and reflection processes of tungsten.

The calculations assume a trace impurity limit and the code calculates the impurity density for a fixed background plasma. In order to make more self-consistent calculations, it is necessary to couple IMPGYRO to a background plasma code. For this purpose, the coupling activity of IMPGYRO to the edge plasma code package SOLPS [2] was started and IMPGYRO has been extended to calculate the particle, momentum and energy sources/sinks due to the interaction between the background plasma and tungsten impurities as a first step [3]. These parameters are transferred from IMPGYRO to SOLPS in the coupling procedure. Based on these improvements, initial results of the coupling of SOLPS and IMPGYRO are presented and discussed in this study.

2. Coupling Scheme

SOLPS calculates the following physical quantities: 1) background ion and electron densities n_i and n_e, 2) flow velocities parallel to the magnetic lines of force $u_{\|}$, 3) electron temperature T_e, and 4) ion temperature T_i. These quantities are transferred to IMPGYRO. Using these quantities, IMPGYRO calculates the following source and sink terms in a trace-particle approximation from propagating the tungsten test particles: 1) the particle source S^P, 2) the parallel momentum source $S^{M_{\|}}$ and 3) the energy source S^E for the background plasma calculation.

As the species followed by IMPGYRO also carry charge, some of the plasma ionic charge is "hidden" from the B2.5 (the plasma fluid part of the SOLPS package) calculation. This means the electron density within B2.5 can no longer be considered as the sum of its ion densities times their charge. It was necessary to recast the formulae where the equality between the electron and total B2.5 ionic densities was implicitly used. In addition to the sources described above, additional information from IMPGYRO must be passed to B2.5, namely the W ion densities, fluxes and average energies. With these data, it is possible to recover a fully

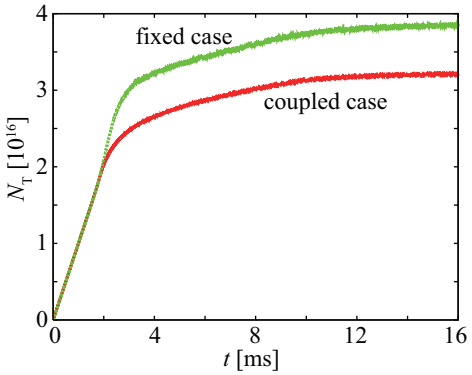

Fig. 1 Time evolution of the total number of tungsten particles in the system

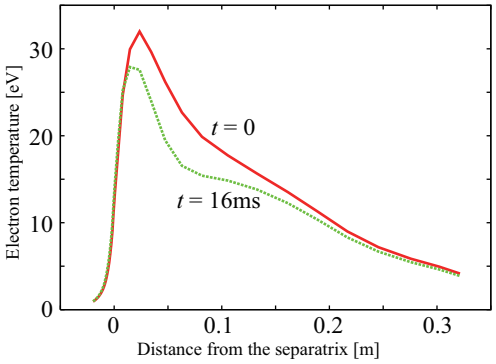

Fig. 2 Electron temperature profiles along the outer divertor plate

self-consistent plasma description and system of equations. It is the results obtained with this self-consistent treatment that we will present in the next section.

3. Test calculation and results

The initial test calculation of the SOLPS-IMPGYRO coupling code has been made with the ASDEX Upgrade geometry. Prior to the coupling calculation, the initial background plasma has been obtained by SOLPS under the following conditions: 1) Only deuterium is taken into account as background ion species in this SOLPS calculation, 2) the deuterium ion density at the core-interface boundary is set to be $2.0\times10^{19}\,\mathrm{m}^{-3}$, and 3) input power of $Q_e = Q_i = 1.0\mathrm{MW}$ has been assumed. After reaching the steady-state solution of the SOLPS stand-alone run without tungsten impurities, the coupling run has been started.

A tungsten point source is assumed at the outer mid-plane. As was discussed in [4], the ICRH antennae located at the outer mid-plane have been identified as a possible source of tungsten impurity generation. For simplicity, the test tungsten neutrals are constantly fed with a generation rate $1.0\times10^{19}\,\mathrm{m/s}$ with the initial velocity $v = 0$.

Figure 1 shows the time evolution of the total number N_T of tungsten particles in the system. The result of the coupled calculation is compared with that of the fixed background calculation. As shown in Fig. 1, both cases reach quasi-steady state but the total number N_T for the fixed case becomes 1.2 times larger than the one for the coupled case.

In order to understand the suppression of N_T, the electron temperature profiles just in front of the outer divertor plates are shown in Fig. 2. Electron temperature decreases mainly due to the radiation of tungsten impurities in the coupled case. The sheath-potential drop and the sheath acceleration of the tungsten ions towards the wall also decrease. Then, the incident energy of the tungsten ions becomes smaller. The re-emission yield tends to become smaller with decreased incident energy. This makes the re-emission yield smaller, which leads to the difference of N_T between the two cases.

4. Summary

Coupling the Monte-Carlo impurity code IMPGYRO and the edge plasma code package SOLPS has been undertaken to achieve a more consistent treatment of tungsten as an impurity together with a background plasma. A test calculation has been performed under simple assumptions for the impurity generation to check the coupled code. The background electron temperature decreases in the coupled calculation in comparison with the fixed background case due to the electron radiation loss by tungsten impurities. The resultant suppression of further impurity generation leads to the quasi-steady state in the coupled calculation. These initial test calculations give us confidence that a self-consistent IMPGYRO and SOLPS coupling has now been achieved. Further code validation will be pursued applying more realistic conditions and making comparisons with experiments.

Acknowledgments

This study is partially supported by a Grant-in-Aid for Scientific Research of the Japan Society for the Promotion of Science.

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