Integrated Two-Dimensional Plasma/Neutral Transport Modeling from Core to the Wall in KSTAR Discharge

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Introduction

More external parameters are noticed to get a higher core plasma performance as proceeding research on the fusion tokamak. In several KSTAR long-pulse discharges, the performance degradation seemed to be caused by the accumulation of the impurity transported from the wall is observed. On the other case, the core plasma is changed with higher temperature and lower density at the pedestal region during the magnetic field configuration transition from the Lower Single Null(LSN) to the Connected Double Null (CDN), which leads the performance higher. These imply that the conditions decided at the wall affect the core plasma through the particle transport or the geometric change. Therefore, in this paper, an integrated two-dimensional plasma/neutral particle transport simulation modeling is presented which covers the entire tokamak include the core, edge-pedestal, SOL, and the region near the wall. C2 [1] is employed as a main 2D plasma transport solver with a 2D neutral particle transport solver, GTNEUT which uses transmission and escape probabilities method considered a computationally efficient alternative to the traditional Monte Carlo method [2]. These solvers are worked on the domain prepared by the grid generator, VEGA2.0 [3], which covers the whole tokamak region. TRIASSIC [4], a flexible integrated suite of codes using IMAS/IDS [5] storage format, is used to orchestrate the above modeling codes and several others.

Workflows

To reproduce the experiment, the simulation is started with the fitted kinetic profiles and the EFIT based equilibrium. The core equilibrium is updated by CHEASE [6] and the external particle/energy sources by neutral beam are provided by NUBEAM [7]. GLF23 [8, 9] and NCLASS [10] are used to decide the core turbulent and neoclassical transport, respectively. Near the pedestal region, because of the difficulty of the consideration 2D pedestal model, a power-balanced transport model, calculated from the initials kinetic profiles and accordingly sources, is employed. These prepared core data is placed poloidal symmetrically to the 2-dimensional core grid generated by VEGA2.0. So, for now, the 2D effect of the core plasma is driven by the neutral particle distribution only. The kinetic profiles in the SOL, private region, and the region near the wall are prepared to smoothly changed from the separatrix value to the wall boundary condition. Especially a hyperbolic tangent function is used to connect the cross-field transport coefficient values at the separatrix to the certain input anomalous values at the end of SOL (Inactive X-point). The anomalous values firstly started from the commonly used in the boundary solvers as $D_p = 0.5\ [m^2s^{-1}]$ for ion particle and $\chi_e = \chi_i = 1.0\ [m^2s^{-1}]$ for the temperatures. The boundary conditions at the wall are all constant. Finally, the C2 and GTNEUT solve the plasma and neutral particle density for a given time interval. For the update of the equilibrium and the transport model, core plasma profiles are surface averaged.

Because it is a simulation modeling that solves the whole tokamak regions simultaneously, the workflow is subdivided for each objective to get a converged result. First of all, it is needed to get a reliable core plasma profile in the fixed other region. We can calibrate the fitted kinetic profiles or the pedestal model in this stage. Then, other regions are included with the given initial conditions. The cross-field transport coefficients and wall boundary values can be changed to control the separatrix values. If there are experimental data in the SOL, we can search the gas puff rate, Γ_D, by scanning. For this injected gas, the ion profiles will be changed. So, the process is started again from the calibration of the pedestal model. This procedure can be conducted iteratively for a few rounds to get a converged result.

Validations and Applications

This simulation modeling is tested with a time slice of the discharge of KSTAR which is in the steady-state and has the same operation with the divertor heat flux diagnosed discharge [11]. In this time slice, the magnetic field is $B = 1.722\ [T]$, plasma current is $I_p = 0.513\ [MA]$, and the heating power is totally $P = 3.2\ MW$. ASTRA [12] is used for the benchmark. Figure 1 shows a comparison of the total energy and the kinetic profiles. The developed model results in more diminished energy than the ASTRA, which mainly caused by the difference in the electron temperature at the pedestal region. This is because, in the 2D model, the region near the

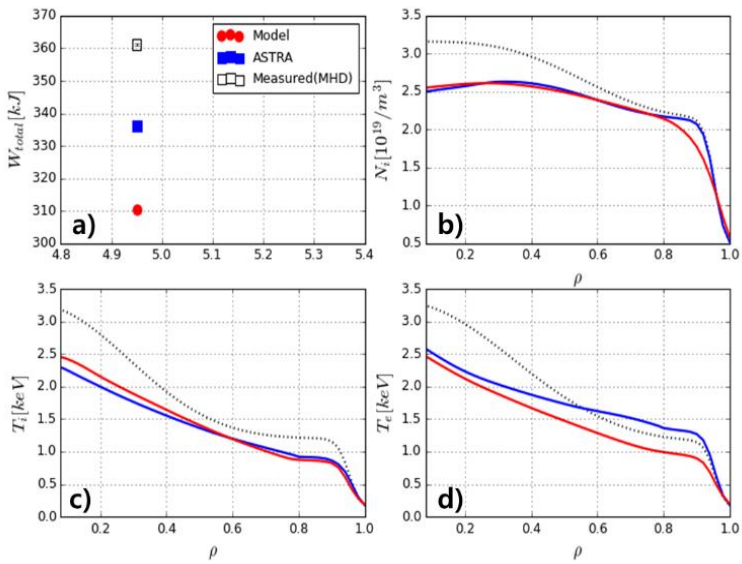

Figure 1. a) Predicted total energy from the model and ASTRA and measured $\mathbf{W_{mhd}}$. b) Ion density, c) ion temperature, and d) electron temperature profiles.

magnetic axis is excluded due to geometrical and numerical difficulties. When the extrapolation is performed to the excluded region, the difference occurs between the results of the model and ASTRA which leads to the different current profiles. To keep the total current, the bootstrap and ohmic current are changed at the pedestal region. The ohmic current modifies the ohmic heating near the region which gives a source to the electron temperature. This situation can be handled to minimize by using a proper method or controlling the calculation domain.

The next is the comparison of the SOL plasma solved with or without the region near the wall, which is the main keyword of this paper. After getting the converged plasma states, the same controllable variables are used in the simulation in the SN domain only including the core, SOL, and private region. The Neumann boundary condition is used for the SOL and private region. As shown in figure 2, the converged ion temperature profiles are constantly deviated between each simulation from the boundary to the core. This is because the wall boundary condition sustains the temperature low and the whole tokamak simulation has a larger divertor space, which consumes the heat flux, than the SN case. From this, the simulation on the whole tokamak region has advantages on the set the boundary conditions reliably.

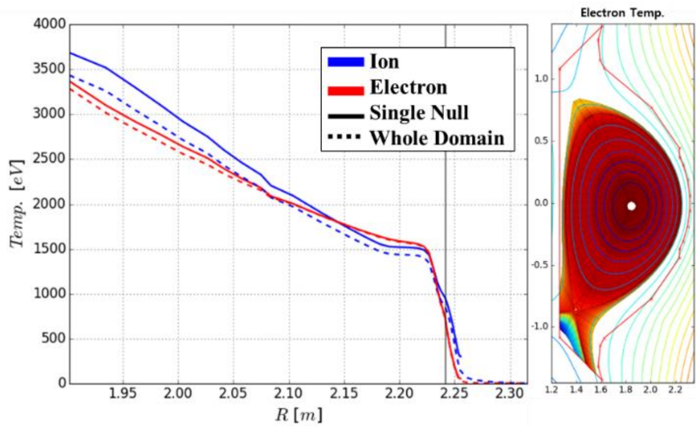

Figure 2. Comparison of the temperature solved in SN and whole domain (Left). 2D contour plot of electron temperature in SN

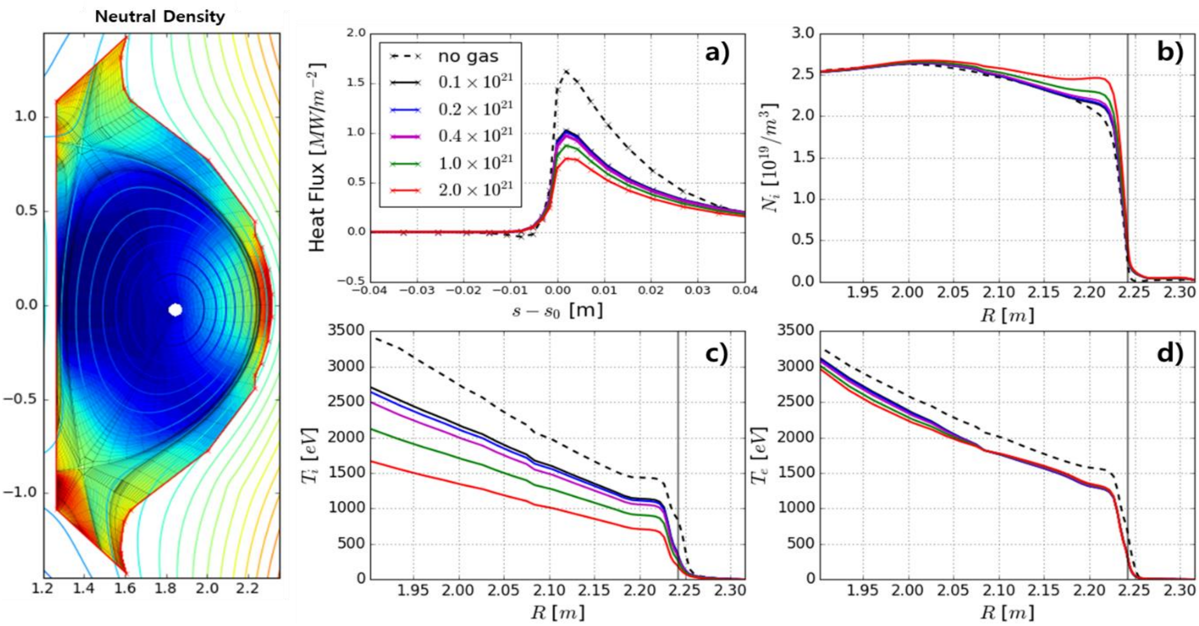

Figure 3. Neutral particle contour plot which shows the location of gas puff. a) lower outer divertor heat flux for each gas puff rate. b), c) and d) show the kinetic profiles for each case

The divertor heat flux, $q_{\perp,div}$ is calculated at the both inner and outer divertor for figuring out the neutral gas density level. In the experimental data, the $q_{\perp,div} \cong 0.5\ \mathrm{MWm^{-2}}$ at the outer target. With no gas injection, $q_{\perp,div} \cong 1.5\ \mathrm{MWm^{-2}}$ as shown in figure 3. Obviously, the results show the $q_{\perp,div}$ decreases in proportion to the increasing Γ_D. However, the ion density at the Low-Field Side (LFS) mid-plane gets fueled dramatically while the ion temperature monotonically shrinks. So, $\Gamma_D \leq 1.0 \times 10^{21}$ seems to enough to sustain the pedestal of ion density. The overestimated charge exchange with neutral particle sink by the assumption of cold neutral particle from gas puff may be the reason for the too low ion temperature.

Conclusions

An integrated 2D simulation modeling is presented to understanding the confined plasma with consideration of the effect from the wall. By conducting the workflow, we can get plasma kinetic profiles from the wall to the core, however, many points of improvement are appeared such as simulation at the magnetic axis, the necessity of a reliable pedestal model, or the consideration of the warm neutral particles. Once these are implemented, this simulation modeling can be used for the research on the plasma performance affected by the impurity transport or the magnetic field transition.

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