Modeling of the SOL and Divertor Region in NSTX and Prediction to KSTAR

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1. Introduction

As the behavior of edge plasmas plays very important role in entire plasma confinement, it is a major concern to develop accurate and reliable codes to understand boundary plasmas in various edge conditions for a tokamak. The KTRAN code [1] is a two-dimensional edge transport code combining plasma, neutral and impurity simultaneously for the scrape-off layer and divertor region. In this code, plasma is calculated by single fluid transport equations, on the other hand neutral and impurities are computed by the Monte-Carlo method.

In this paper, the KTRAN code is validated using NSTX (National Spherical Torus eXperiment) experimental data, where various transport coefficients and boundary conditions at separatrix and divertor target plates are set from diagnostic data of the NSTX edge region. As a result of numerical simulations, the plasma density and heat flux profile in the divertor region is calculated and compared with experiments.

After the validation, predictive simulations are carried out for the KSTAR divertor with particular focus on the effect of gas puffing to heat flux reduction for the baseline operation mode in KSTAR.

2. Simulation of NSTX experiment

NSTX (R = 0.85 m, a < 0.67 m, R/a > 1.27) has been studied for especially divertor phenomena including radiative divertor and divertor geometry effects in tokamaks [2]. In this work, we simulate a NSTX discharge (shot 128797) that is a high performance 1.2 MA H-mode discharge with NBI heating of 6 MW and triangularity of about 0.8. The KTRAN's computational domain for the NSTX simulation is outer lower SOL & divertor (horizontal graphite target) region. And the mesh is constructed by CARRE [3] using EFIT equilibrium data of NSTX (128797, 543ms).

We use magnetic diagnostic data to obtain the input values in KTRAN. It solves the single fluid equation for plasma, thus requires some boundary condition at separtrix line. For density at separatrix, n_{sep} = 6.79 x 10^{18} m^{-3}, is setted by interpolation between the diagnostic points. For temperature at separatrix, T_{sep} = 110 eV, is assumed by ion temperature data. As the data from charge-exchange spectroscopy does not contain the separatrix region, we used interpolation to obtain the value.

We use some assumptions to estimate the power flowing into outer lower SOL from the core as follows: ~15% beam ion loss, ~40 % core radiation loss, 4:1 out/in asymmetric power distribution [4,5]. To compare the experimental data to the simulation results, we adjust the particle diffusivity D, electron thermal diffusivity χ_e and recycling ratio γ_{recy} values. These D, χ_e, and γ_{recy} coefficients are assumed as constants for the whole computational domain.

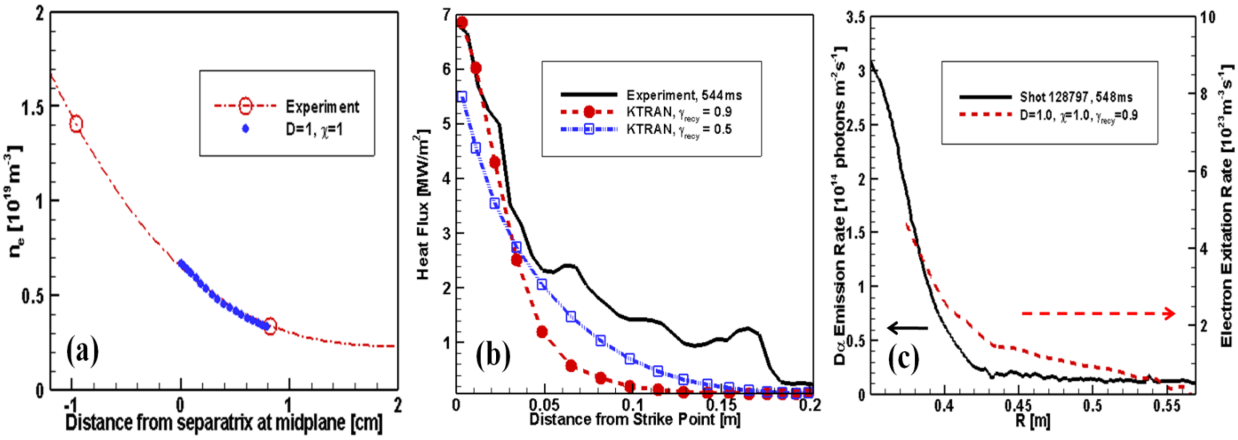

Figure 1. (a) Electron density profile at midplane, (b) heat flux profile and (c) D_α signal and electron excitation rate on divertor target

The simulated electron density profile at the midplane with D = 1 m^2/s, χ_e = 1 m^2/s is shown in Figure 1 (a). It agrees well with the experimental one in the SOL.

The heat flux obtained experimentally at 544 ms is compared to simulations with γ_{recy} = 0.9 and 0.5, respectively in Figure 1 (b). For γ_{recy} = 0.9, calculated peak load on NSTX divertor target is quite accurate. However farther from the strike point, i.e. over than 0.05m, it shows relatively smaller value than experimental one. It is expected to be caused by heat loss from active recycling cooling and unexpected experiment condition (radiation distribution, varying coefficients with position, etc). If the recycling ratio is reduced to 0.5, the broader heat flux profile is obtained than γ_{recy} = 0.9; the peak heat flux is slightly reduced and that in over than 0.05 m is increased. The difference in over than 0.05 m can be explained by different recycling ratio compared with the strike point region.

We compare the experimental D_α emission with electron excitation rate in Figure 1 (c). We utilize D_α data at 548ms for comparison. Since calculation of D_α emission is not available in the current version of KTRAN, electron excitation rate is shown instead for qualitative comparison. As shown in Figure 1 (c), the calculation reproduces the experimental trend well.

3. Simulation of heat flux on KSTAR divertor

The simulation are carried out in double-null geometry for baseline operation mode (phase I, plasma current I_p = 1.2 MA, toroidal magnetic field 2 T, total heating power is 8 MW). The heat flux on the KSTAR divertor is calculated and shown in Figure 2. Considering the acceptable peak heat fluxes are known to be about 5 MW/m^2 (or 10 MW/m^2 with a active cooling) [6], the peak heat flux ~ 7 MW/m^2 shown in the figure is somewhat high. Therefore, active cooling like gas puffing or impurity injection is essential.

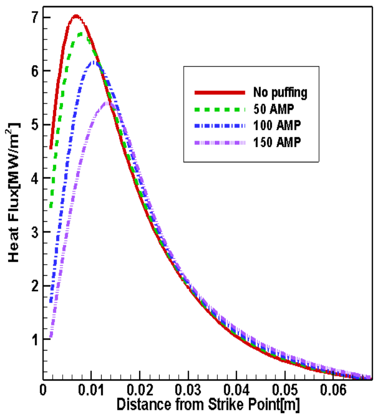

Figure 2. heat flux profiles with gas puffing

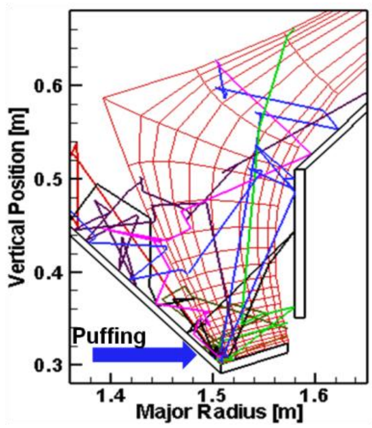

Figure 3. Puffing gas position and the trajectory of gas

In this context, further simulation is carried to find out the effect of reducing heat flux on the KSTAR divertor by puffing deuterium into the divertor region. In this simulation, in front of outer strike point is considered as the position of gas puffing and shown in Figure 3. As puffing gas flux density is increased, the peak heat flux is decreased. When the puffing gas flux density is 150 AMP (6 x 10^{18} /s), the expected peak heat load is about 5.4 MW/m^2. It is also expected that more gas flux density into the divertor region will decrease the heat flux on target plate.

Once the puffing gas into the divertor region, it makes more recycling reaction in adjacent outer strike point and affects the local ion temperature decreased. Since physical sputtering reaction as a source of impurity generation is dependent with ion temperature, the impurity yield is also reduced. The reduced impurity in SOL and divertor region will give more safety for steady state operation. The transition of carbon density is shown in Figure 4.

In this simulation, it is used for puffing gas as deuterium only not D_2 gas. It is expected more heat dissipation is occured with using D_2 gas since it has dissociation reaction. Therefore if the KSTAR use D_2 gas for puffing gas, it will reduce more heat flux on divertor target than this simulation results.

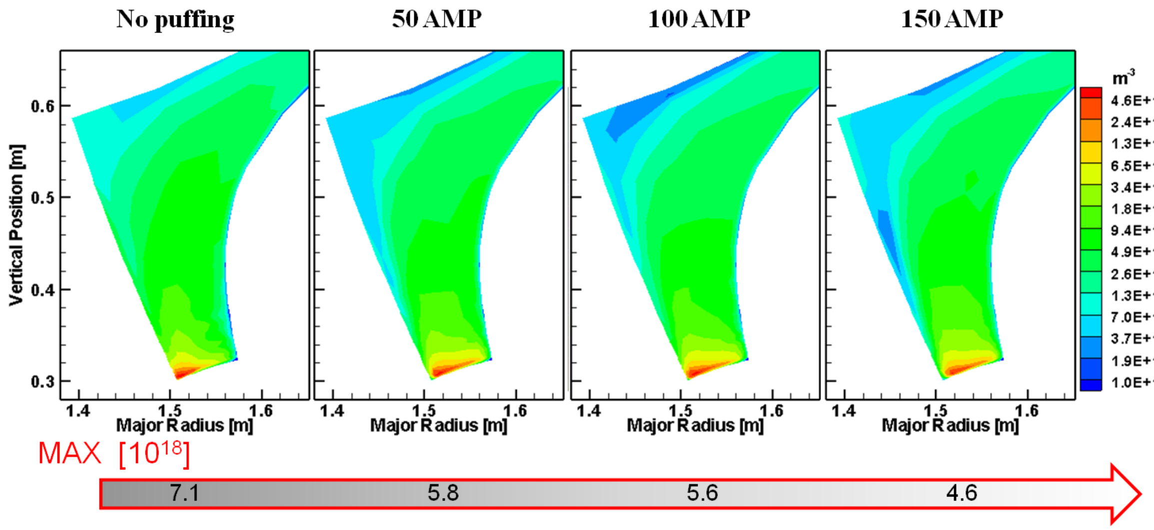

Figure4. The transition of carbon density as puffing gas is increased

4. Summary

The modeling of SOL and divertor region in NSTX and prediction to KSTAR is performed with the KTRAN code. The density profile and peak heat flux of NSTX experiments is reproduced. Shape of D_α Profile is also investigated by electron excitation ratio. The prediction of heat flux on the outer lower divertor in KSTAR is calculated for the baseline operation mode in KSTAR. The peak load is about 7 MW/m^2 which is higher than the engineering limit. As a method to reduce the peak load, the effect of gas puffing is simulated. As the puffing gas flux density increases, peak heat flux is further reduced and the location of the peak heat flux moves outward from the strike point.

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