Simulation of Tokamak SOL and Divertor Region and Heat Flux Mitigation using Gas Puffing

Jin-Woo Park[1], Joon-Wook Ahn[2], Deok-Kyu Kim[3], Hyunsun Han[4], Seung Bo Shim[5], Hae June Lee[5], Sang Hee Hong[1] and Yong-Su Na[1]

[1] *Department of Nuclear Engineering, Seoul National University, Seoul, Korea*

[2] *Oak Ridge National Laboratory, Oak Ridge, USA*

[3] *Agency for Defense Development, Daejeon, Korea*

[4] *National Fusion Research Institute, Daejeon, Korea*

[5] *Department of Electrical Engineering, Pusan National University, Busan, Korea*

1. Introduction

Recently, KSTAR achieved H-mode successfully and it was identified that the edge condition is very important to achieve an H-mode. The KTRAN code [1] developed at Seoul National University (SNU) is a self-consistent computational code capable of analyze and predict the characteristics of the edge region which is a two-dimensional, fully coupled, fluid-kinetic hybrid code for calculating plasma, neutral and impurity particle transport in the scrape-off layer and divertor region.

In this work, firstly, numerical results of the KTRAN code are compared with the experimental results for Single Null (SN) plasmas in National Spherical Torus eXperiment (NSTX). NSTX is a medium size (R = 0.85 m, a < 0.67 m) Spherical Torus (ST) [2] and has been studied especially divertor phenomena. Secondly, a simulation is carried out for the SOL and divertor region in a KSTAR baseline operation scenario. Then as a method to handle high heat load, gas puffing into the divertor region with deuterium and argon is studied numerically for KSTAR.

2. Simulation of the NSTX SOL and divertor region

We simulate the outer lower SOL and divertor region of a NSTX experiment discharge (Shot 128797, 543 ms) that is an H-mode discharge with $\beta_N = 4.3$ and $q_{95} = 6.2$ at $P_{NBI} = 6$ MW. The calculation grid of KTRAN for the NSTX discharge is constructed by the CARRE code [3]. The input and the boundary condition for the simulation are obtained from the experimental diagnostics such as the Thomson scattering and the Infrared (IR) camera. More detailed conditions for the simulation can be found in [4].

The simulation results are shown in figure 1. Firstly, the electron density profile at the midplane is compared in figure 1 (a). In the simulation we assume the density profile at the edge can be fitted by a spline function. Based on the assumption, we calculate the electron density at the separatrix and set the boundary condition as 6.0 x 10^{18} m^{-3}. With D = 1.0 m^2/s, χ_e = 1.0 m^2/s, the calculated density profile agrees well with the experimental data compared with the case with D = 0.5 m^2/s, χ_e = 1.0 m^2/s.

Secondly, the heat flux profile on the divertor plate is compared in figure 1 (b). Calculation was carried out varying χ_e for a fixed value of D = 1.0 m^2/s. With χ_e = 0.5 m^2/s, we obtained the peak heat flux similar to the experimental one. However, the gradient of the measured heat flux profile changes at r ~ 0.05 m from the midplane separatrix location, and this leads the whole profile to consist of 2 zones, the near SOL with steep gradient($r \leq 0.05$ m) and the far SOL with smaller gradient($r \geq 0.05$ m). This can be explained by non-uniform transport coefficients in the NSTX SOL region. To verify the effect of the transport coefficient, we scanned χ_e from 0.5 to 4 m^2/s. As χ_e is increased, the heat flux profile broadens with the reduction of peak heat flux. When χ_e reaches 4 m^2/s, the gradient of heat flux profile agrees with the experiment. This result implies that the radial heat diffusion coefficients for $r \geq$ 0.05m may be larger than, with different spatial distribution, the one for the near SOL ($r \leq$ 0.05m). A similar behavior is also reported in other NSTX discharges [5].

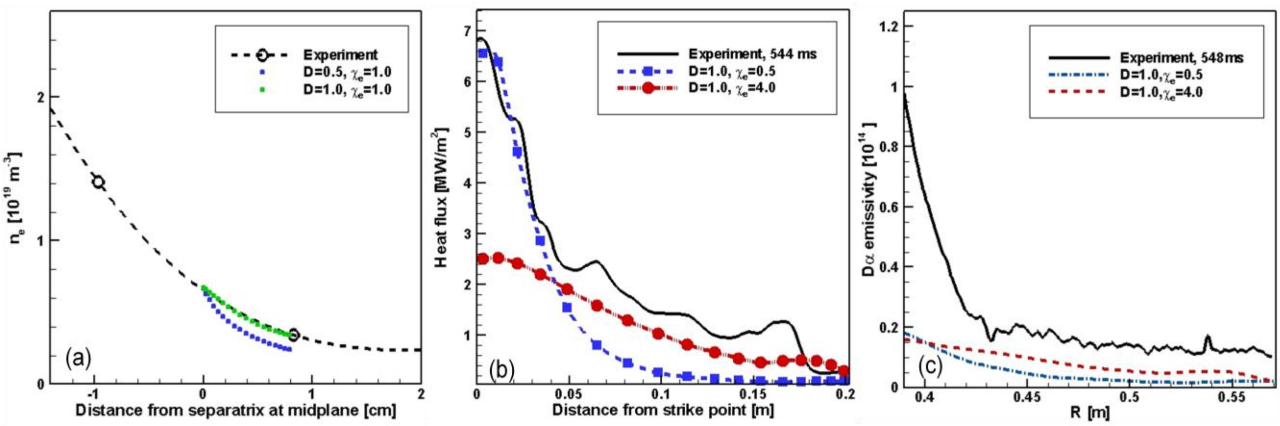

Figure 1. (a) Electron density profile at midplane, (b) heat flux profile and (c) D_α emissivity on the divertor target

Finally, the D_α emissivity profiles are compared in figure 1 (c). Because the original version of KTRAN was not capable of calculating the D_α emissivity [1], direct comparison between the experimental D_α data and the simulation result was not possible in the past. A module for the calculation of D_α emissivity was recently developed and implemented in KTRAN. This module is based on multiplication of the reaction rate coefficients for the deuterium excitation and the spontaneous radiative transition rate [6]. Here, we assume the D_α radiation is emitted only from the deuterium neutral particles which are located on the divertor surface.

The overall D_α emissivity profile from calculation is lower than the experimental value although the gradient in the far SOL is similar. It is expected to be caused by lower heat flux in the simulation as shown in figure 1 (b). And the assumption which we only consider the deuterium on the divertor surface is another reason. The big discrepancy in the near SOL is also reported in other studies [7, 8]. It is thought to be the experimental D_α emissivity data is included the radiation also emitted from the inner divertor region.

3. Simulation of the gas puffing in the KSTAR divertor region

A simulation was carried out to find the effect of gas puffing focusing on heat flux mitigation for KSTAR baseline operation mode (phase I, I_p = 1.2 MA, B_t = 2 T, P_{tot} = 8 MW). In this work, the plasma density is set to be 3 x 10^{19} m^{-3} and the initial temperature is assumed to be 100 eV for boundary condition. Graphite target is considered for the KSTAR divertor.

The peak heat flux onto the outer lower divertor is expected to reach about 6.4 MW/m^2 at the stationary condition of the KSTAR baseline operation mode. This value is over the typical engineering limit (~5 MW/m^2), but it is acceptable with the active divertor cooling scheme [9]. In order to investigate the potential as a heat mitigation method, the deuterium and argon gas puffing in the divertor region was simulated in this study. The puffing position is set to be in front of the strike point.

The simulation results are shown in figure 2. After the gas puffing, the peak heat flux is reduced with puffing rate over a certain value; 1.0 x 10^{20} /s for deuterium and 5.0 x 10^{18} /s for argon. As expected, the heat flux is more reduced as the gas puffing rate increased. To meet

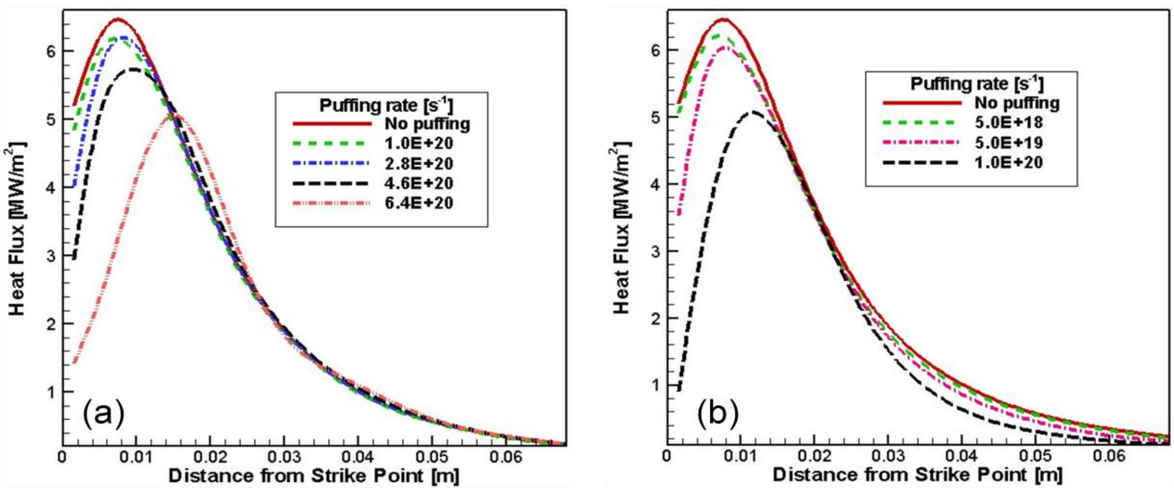

Figure 2. Heat flux mitigation with (a) deuterium and (b) argon puffing

the engineering limit of the divertor peak heat load, the gas puffing ratio should be above 6.4 x 10^{20} /s and 1.0 x 10^{20} /s for deuterium and for argon, respectively.

Furthermore, the reduced heat flux would lead to a lower sputtering reaction at the divertor and therefore a lower carbon impurity source. This effect is presented in figure 3. When the deuterium puffing rate reaches 6.4 x 10^{20} /s the peak heat flux is reduced to 5 MW/m^2, and the peak carbon density is reduced by 25 % compared with no gas puffing.

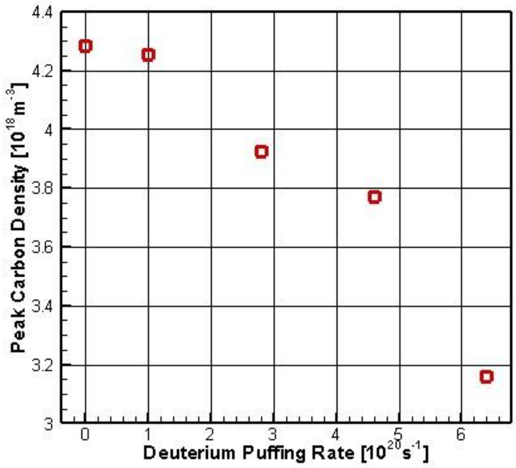

Figure 3. The reduced peak carbon density by deuterium puffing

4. Summary

A 2 D SOL-divertor simulation was carried out for a NSTX H-mode discharge and the result was compared with the measurement. With D = 1.0 m^2/s, the electron density profile agrees well with the experimental one. The heat flux and D_α emissivity profiles show similar gradient to the experimental one, with some assumption of transport coefficients. From the profile analysis, it is expected that there are two distinct regions in the SOL with different radial transport properties. χ_e is thought to be larger in far SOL region than the near SOL. The effect of gas puffing for the heat flux mitigation was also studied in KSTAR. It is found that each of the deuterium and argon gas over certain value could mitigate the heat flux at the divertor. As a result, the peak carbon density is reduced by 25 % compared to the one without puffing. This method therefore provides a positive prospect for the reduced heat flux regime for the future KSTAR operation.

References

[1] D.K. Kim and S.H. Hong, Phys. Plasmas **12** (2005) 062504

[2] Ono M. et al., Nucl. Fusion **40** (2000) 557

[3] Marchand R and Dumberry M, Comp. Phys. Comm. **96** (1996) 232

[4] J W Park et al., Proc. of the 37th EPS Conf. on Plasma Physics, Dublin (2010) P2.151

[5] J- W Ahn et al., Physics of Plasmas **15** (2008) 122507

[6] L C Johnson, The Astrophysical Journal, **174** (1972) 227

[7] D P Stotler et al., Contrib. Plasma Phys. **50** (2010) 368

[8] D P Stotler and C F F Karney, Contrib. Plasma Phys. **34** (1994) 392

[9] R Stambaugh et al., Nucl. Fusion **39** (1999) 2391