Modelling of helium plasma transport in linear divertor simulator NAGDIS-II with UEDGE

D. Nishijima[1], A. Yu. Pigarov[2], T. D. Rognlien[3], N. Ohno[1], E. M. Hollmann[2],

S. Takamura[1], and S. I. Krasheninnikov[2]

1. Nagoya University, Nagoya 464-8603, Japan
2. University of California at San Diego, La Jolla, CA 92093, USA
3. Lawrence Livermore National Laboratory, Livermore, CA94551, USA

1. Introduction

In recent years it was found that divertor plasma simulators like NAGDIS-II and PISCES exhibit many features similar to that found in edge plasmas of large fusion devices like tokamaks. Therefore, taking into account the rather simple geometry, stationary operational conditions, and relatively small scale of experiments, divertor simulators are considered to be a useful test bed for verification of different plasma physics models, in parallel with or even before applying these models to tokamaks.

One example of this is the verification of theoretical concept of Molecular Assisted Recombination (MAR) [1], which can strongly affect the divertor detachment process. MAR, involving rather complex atomic physics of hydrogenic species, was confirmed first on NAGDIS-II and later observed in the Alcator C-Mod tokamak [3].

Another example is the verification of the concept of non diffusive cross-field plasma transport. This has been observed in tokamaks [4] and is associated with so-called plasma blobs [5,6]. Recent experiments in PISCES[7], LAPD[8], and NAGDIS[9] linear devices observed blobs similar to those seen in tokamaks.

In-depth comparison of theoretical results with experimental observations requires an integrated approach. It should include detailed theoretical calculations, a precise account of spatial and temporal variation of plasma parameters in the experiment, and include synergistic effects caused by different phenomena (e. g. cross-field plasma transport plus MAR). The 2D plasma transport code UEDGE [10] includes a correction for convective transport, and calculates atom-molecular process precisely by using detailed databases. With these advantages, UEDGE is expected to be an optimum code for analyzing detached plasmas and non diffusive transport in linear divertor simulators. A systematic analysis of linear divertor simulators has been planned using UEDGE.   In this paper, a typical attached helium plasma in NAGDIS-II is analyzed with UEDGE using a cylindrical plasma model. Detached plasmas and hydrogen-isotope plasmas will be analyzed in the future.

2. Simulation model

Figure 1 shows a schematic view of the linear divertor plasma simulator NAGDIS-II. The plasma test region is 0.18 m in diameter and 2.0

Fig. 1. Schematic of NAGDIS-II

m in length. Helium gas is used at a pressure of 1.0 Torr in the discharge region, with He plasma produced by a TP-D type discharge between a LaB$_6$ cathode and hollow anode with a 24mm aperture.   An axial magnetic field of 0.2 T is used. Radial profiles of plasma density and electron temperature are measured with a single Langmuir probe at positions P1(z = 0.25m), P2(z = 1.0m) and P3(z = 1.4m), where the origin of z = 0 is set at the outlet of the anode. The target plate, which is electrically floating, is located at z = 2.0 m. Figure 2 shows a non-uniform numerical mesh employed in the UEDGE calculations, which corresponds to the rectangular area enclosed by a dotted line in Fig. 1. Azimuthal symmetry of the

Fig. 2. Numerical mesh for NAGDIS-II

plasma is assumed. Electrostatic plasma sheath conditions and the Bohm criterion are employed at the end-plate (C-D) and the limiter (A-B). At the outer wall (B-C), the energy transmission factors are specified for ion and electron heat fluxes to wall, whereas the gradient scale-lengths (0.02-0.1 m) are prescribed to ion densities and velocities. There is a mirror-symmetry plane (O-A) at z = 0 m and 0 < r < R$_{lim}$=0.015 m. In the plasma supply region, 2D profiles are set for input sources of plasma particles, momentum, and power. The radial and axial source profiles in this region are given by Gaussian distributions with a half-width values of R$_{lim}$ and L_{sp}, respectively. For attached plasmas, L_{sp} is an important fitting parameter mentioned later.
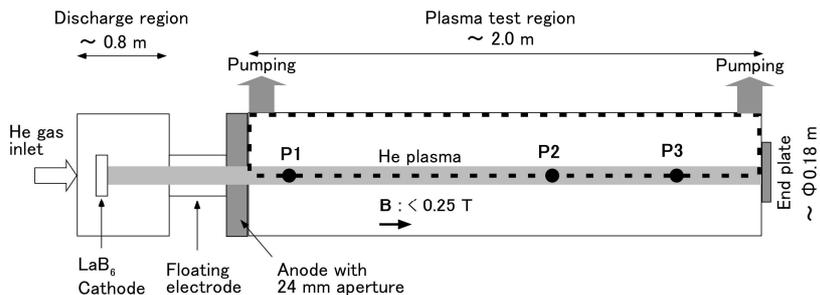
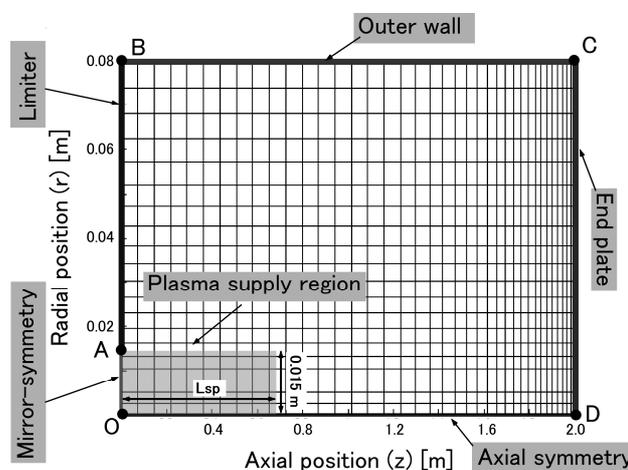|	$D_\perp$(m2/s)	$X_\perp$ (m2/s)	V_{conv}(m/s)
A$_{00}$	0.4	0.8	1
A$_{r0}$	0.1	0.2	800
A$_{0L}$	0.2	0.4	0.1
A$_{rL}$	0.05	0.1	80
β	0.5	0.5	0.7
γ	1.1	1.1	0.5

The cross-field transport coefficients: diffusion coefficient $D_\perp$, thermal conductivity $\chi_\perp (m^2/s)$, and outward anomalous convective velocity $V_{conv}(m/s)$, are assumed to be a functions of r and z. The 2D profile of A=$\{D_\perp, \chi_\perp, V_{conv}\}$ is given as follows:

$$A(r,z)= \{A_{00} + A_{r0} [r/R_w]^\gamma\}*[1-[z/L]^\beta] + \{A_{0L} + A_{rL} [r/R_w]^\gamma\} * [z/L]^\beta \qquad (1)$$

,where R_w is the radius of the chamber (=0.08 m) and L is the axial distance from entrance to target (=2.0 m). Equation (1) contains 6 fitting parameters: A_{00}, A_{r0}, A_{0L}, A_{rL}, γ, β, which are listed Table 1. Note, we use the values for $D_\perp$ and $\chi_\perp$ of about the Bohm value and use profiles that mimic the measured T_e dependence. The atomic processes for helium used in this simulation are ionization, charge exchange, elastic collision and recombination.

3. Results and discussions

Figure 3 shows the axial profiles of T_e and n_e calculated with UEDGE for different length L_{sp} of plasma supply region. We find thatin attached plasmas the axial profile of n_e strongly depends on L_{sp}. Experimental data agree with the calculated result using L_{sp} around 0.9 m. This means that plasma supply region expands in the plasma test region, which may be due to energetic electrons accelerated by the discharge voltage in the discharge region, since the mean free path of primary electrons is almost equal to L_{sp}.The calculated profile of T_e also matches experimental data well with L_{sp}=0.91 m.
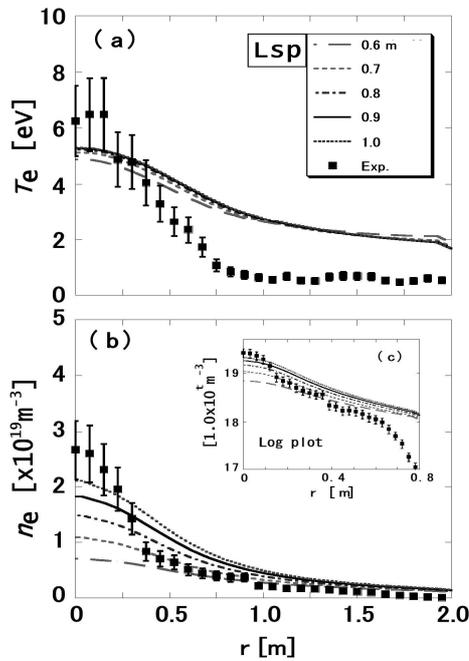

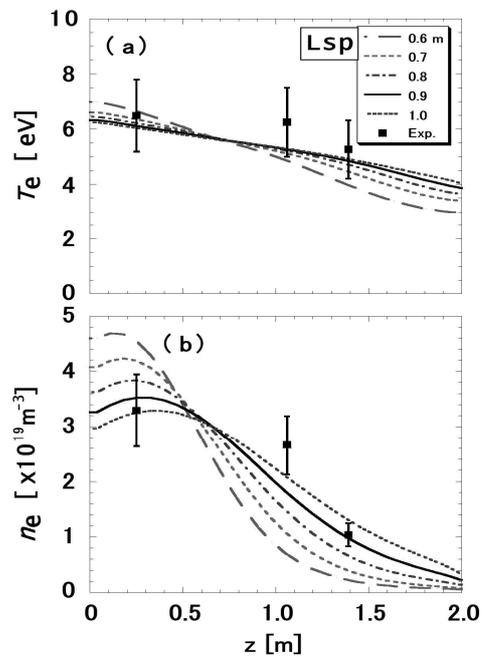Fig. 3   Axial profile of (a) T_e and (b) n_e Fig. 4   Radial profile of (a) T_e and (b)

Figure 4 shows the radial profiles of T_e and n_e at $z = 1.0$ m. Radial profile of n_e also depends on L_{sp} and the larger L_{sp} gives (in combination with fast radial transport) more peaked profiles. The n_e measured in the experiment also shows a peaked radial profile, which is in an agreement with the calculated profile at L_{sp} =0.9 m. On the other hand, the calculated radial

profile T_e showsa weak L_{sp} dependence and matching to the experimental data is relatively poor, because measured profile of T_e rapidly decreases compared to the calculated one. The radial profile of T_e shown by the thick line in Fig. 5 is calculated with simulation parameters tuned mostly to the boundary conditions and the profiles of transport coefficients. The calculated plasma profiles show better agreement compared with the previous case shown by the dotted line.

In summary, experimental data of a He plasma obtained in the linear divertor simulator NAGDIS-II is simulated by the 2D fluid plasma code UEDGE. The simulations show that intermittent convective cross-field transport is an important process (V_{conv} is 800 m/s at the outer
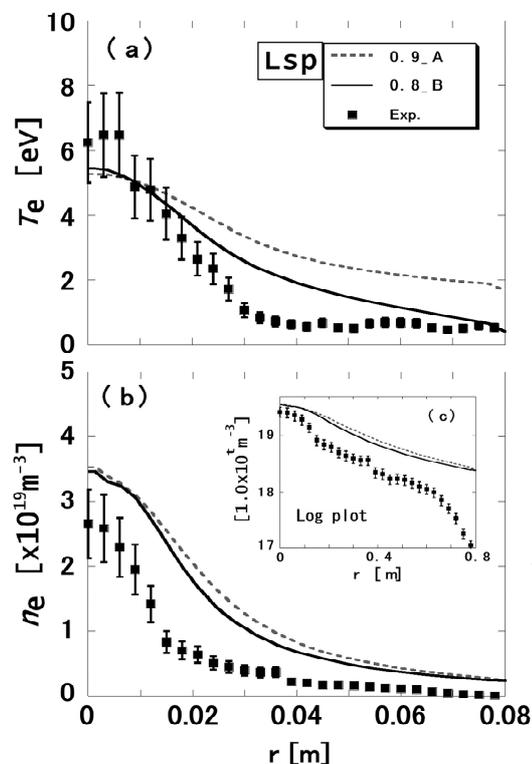

Fig. 5 Radial profile of (a) T_e and (b) n_e

wall). The calculated results indicate the significance of the length of the plasma supply region, *i.e* the input parameter L_{sp}. The existence of energetic electrons, which could have contribution for plasma production in the test region, is anticipated.

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