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Simulation Study on Balmer Line Emission in the CHS Edge Region

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Abstract

Neutral particle behavior in Compact Helical System was studied with the Monte Carlo simulation code DEGAS. Plasma parameters were selected from the discharges with/without the Edge Transport Barrier recently discovered. With the choice of different recycling conditions, atomic/molecular hydrogen distributions were found to change drastically. H_α emission profiles calculated with the Collisional–Radiation model were also dependent upon recycling conditions and existence of the Edge Transport Barrier.

Keywords:

DEGAS, Compact Helical System (CHS), Edge Transport Barrier (ETB), recycling, Collisional – Radiation (CR) model, H_α emission

1. Introduction

Improvement of plasma confinement is an important issue not only for Tokamaks but also for Helical systems. Among various scenarios to do it, formation of the Edge Transport Barrier (ETB) like H-mode is promising one. In Compact Helical System (CHS), the H-mode discharge was produced with the assist of co-direction plasma current. Recently we found a new type of ETB in CHS [1].

This ETB is characterized by the clear drop of H_α emissions. So it is expected that the profile of atomic/molecular hydrogen is one of key parameters to trigger and sustain this ETB. In order to understand the mechanism of ETB, measurement and control of recycled neutral particles are necessary. But until now we have only very limited knowledge on the neutral particle behavior in helical systems, especially in CHS. In order to study the neutral particle behavior, we used the Monte Carlo simulation code DEGAS [2] and DEGAS2 [3].

In the section **2**, we explain the CHS device and our simulation model. In sec. **3**, we present two simulation results obtained with DEGAS version 45 code at National Institute for Fusion Science. One is the relation of neutral density and recycling model. The other is the H_α emission profile calculated with Collisional-Radiation(CR) model. Section **4** is the summary.

2. CHS device and model geometry

CHS is a heliotron/torsatron device with major radius of 1 m and minor radius of 0.2 m. The pole number of the helical field coils is $\ell = 2$ and the toroidal periodic number is $m = 8$. Profiles of plasma density and temperature are measured with YAG Thomson scattering. Li-beam probe is also used to the edge plasma measurement [4].

On the contrary to other helical devices such as LHD, the CHS plasma in the standard magnetic configuration has contact with the inside wall like the material limiter and the neutral recycling becomes dominant there. As the magnetic axis shifts outward, however, the plasma approaches to the magnetic limiter geometry and H_α emission profile will also be changed. So, as the first step to study in CHS, we can neglect the effect of the edge stochastic magnetic field structure and the toroidal asymmetry at least in the standard configuration.

In Fig. 1, our calculation geometry for the DEGAS simulation is shown. Core plasma and "vacuum" region are divided into 50 zones poloidally and into 15 zones radially. Plasma parameters are assumed to be homogeneous along the poloidal direction in our model. Their radial profiles were given from YAG Thomson and Li-beam probe data obtained from the discharge shown in [1]. This assumption must be checked carefully especially in the "vacuum" region, since there exists cold thin SOL plasma and it may be affected by the inhomogeneous divertor magnetic field structure.

Neutral test flights start from the inside wall. The

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Table 1 Calculation condition for the DEGAS simulation. In CASE A ~ D, we change the poloidal extension θ_s of the recycling region. CASE E is the same as CASE D with the exception that n_e and T_e with ETB are used. Molecular densities (n_{H_2}) at right side vacuum region (i.e. $R \sim 115$ [cm] and $Z \sim 100$ [cm] in Fig. 1) are compared.

	Recycling	plasma	n_{H_2}[cm^{-3}]
CASE A	narrow ($\theta_s \sim 57$ [deg.])	without ETB	$\sim 0.5 \times 10^{10}$
CASE B	peaked ($\theta_s \sim 8$ [deg.])	without ETB	$\sim 0.2 \times 10^{10}$
CASE C	broad ($\theta_s \sim 80$ [deg.])	without ETB	$\sim 0.2 \times 10^{11}$
CASE D	uniform ($\theta_s = 180$ [deg.])	without ETB	$\sim 0.2 \times 10^{12}$
CASE E	uniform ($\theta_s = 180$ [deg.])	with ETB	$\sim 0.2 \times 10^{12}$

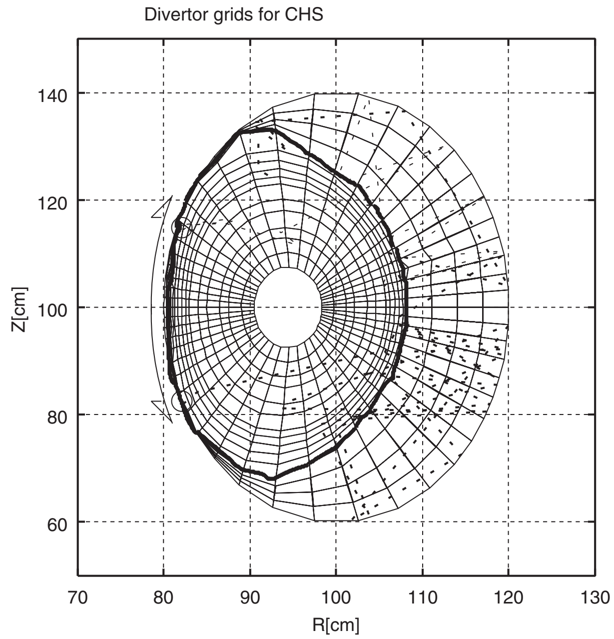

Fig. 1 Calculation geometry for the DEGAS simulation. Open circles are the start points and dashed lines are trajectories of test particles. The boundary between plasma and vacuum is indicated with bold lines. We write the poloidal extention of the particle source as $2\theta_s$. The arc with arrows indicates this extension. (see also Table 1.)

flights and start points of two test particles are also plotted in Fig. 1 with dashed lines and two circles. 50000 test particles (molecules) were launched from the vacuum wall with the room temperature energy. Some particles become fast atoms due to Franck Condon process or charge exchange. We write the poloidal extention of the particle source as $2\theta_s$. The arc with arrows indicates this extension, where we assume that the recycling occurs. We assigned only the wall recycling as the neutral source. So the choice of its strength and profile is very important to explain the experimental observation. Since we have little data on the wall recycling in CHS, we changed values of the angle θ_s and compared the results of calculations each others. (see Table 1)

CASE A is the reference to be compared with previous work [5]. Neutral particles start from the inside wall with $\theta < \theta_s(\sim 57$ [deg.]). While CASE B has more peaked source, CASE C has broad one. In CASE D, particles are assumed to start from whole wall homogeneously. Though areas of the recycling regions are changed in these cases, total number of recycled particles is kept constant. CASE E is the same as CASE D with the exception that electron density (n_e) and temperature (T_e) used are those for the plasma with ETB.

3. Calculation results

3.1 Recycling effect

In Fig. 2, calculation results of 2-dimensional atomic hydrogen density (n_H) distribution are shown. Hydrogen atoms are produced in the interaction between recycled molecules and plasma electrons. In CASE A, the neutral source is located at narrow region of the inside wall (limiter). So n_H distribution also has a peak near the source, which is plotted with the black color. As n_H (also molecular hydrogen density n_{H_2}) decays in the core plasma rapidly, only a few atoms can reach the right-side vacuum region.

In CASE B, which is not included in Fig. 1, n_H profile is more peaked. But in CASE C, many atoms and molecules leak from the source region to the vac-

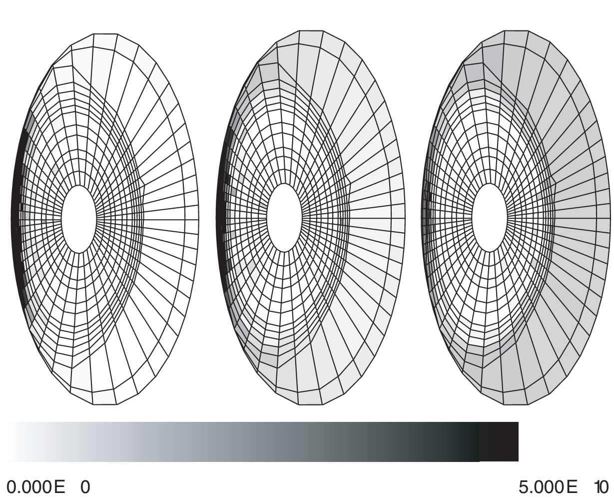

Fig. 2 Hydrogen atomic density (n_H) profile for CASE A, C, D (from the left to the right).

uum. In CASE D, recycled particles from the right half ($\theta_s > 90$ [deg.]) of the chamber wall fill the vacuum region. So n_H reaches to the value of $\sim 10^{10}$ [cm^{-3}] in CASE D. Atomic density is smaller by an order of one than molecular density at this vacuum region. But atomic hydrogen has more energy than molecular hydrogen and can penetrate a little deeply into the core plasma.

In Table 1, we summarize the molecular hydrogen density in the right-side mid plane. If neutrals are assumed to have room temperature, CASE D (and also CASE E) corresponds to the molecular pressure of $\sim 1 \times 10^{-3}$ [Pa] and CASE B is $\sim 1 \times 10^{-5}$ [Pa]. These results suggest that the size of effective recycling area may be deduced from pressure measurement data.

3.2 Balmer series emission

Experimental informations on neutral particles are obtained through Balmer line emission (mainly H_α). According to CR model [7], the population density of an excited level with principal quantum number p is given by

$$n(p) = R_0(p)n_i n_e + R_1(p)n_H n_e + R_2(p)n_{H_2} n_e \quad (1)$$

where population coefficients (R_0, R_1, R_2) can be calculated by Sawada code [6,7]. They are less dependant on plasma density ($n_e = n_i$) and the weak increasing function of T_e. The first term of the right hand side of Eq. (1) is the contribution from recombining ions. In the CHS edge parameter region, R_0 is too smaller than R_1 or R_2 and this term is negligible.

As shown in previous subsection, the molecular hydrogen density is much larger in the edge region than the atomic density, we must estimate balmer series emission not only from excited atoms (i.e. the second term of Eq. (1)) but also from dissociated molecules (i.e. the third term).

In Fig. 3, H_α emission profiles from excited atoms (left side) and from dissociated molecules (right side) are shown. In CHS edge plasma, since population coefficient $R_2(3)$ is smaller than $R_1(3)$, H_α emission from atomic hydrogens is dominant. But contribution from molecular hydrogens can not be neglected around the last closed flux surface (LCFS), where $n_e \times n_{H_2}$ is large.

In the CHS edge plasma, a main reaction of atomic hydrogens is the charge exchange. Molecular hydrogens will be ionized or dissociated with electron impact. These reaction rates are of the same order (10^8 [cm^3/s] or more). So the mean free path (MFP) of Franck Condon atoms is estimated to be about 1cm. MFP of thermally released molecules is much shorter. As the H_α emission from atoms is still large inside of LCFS, it is

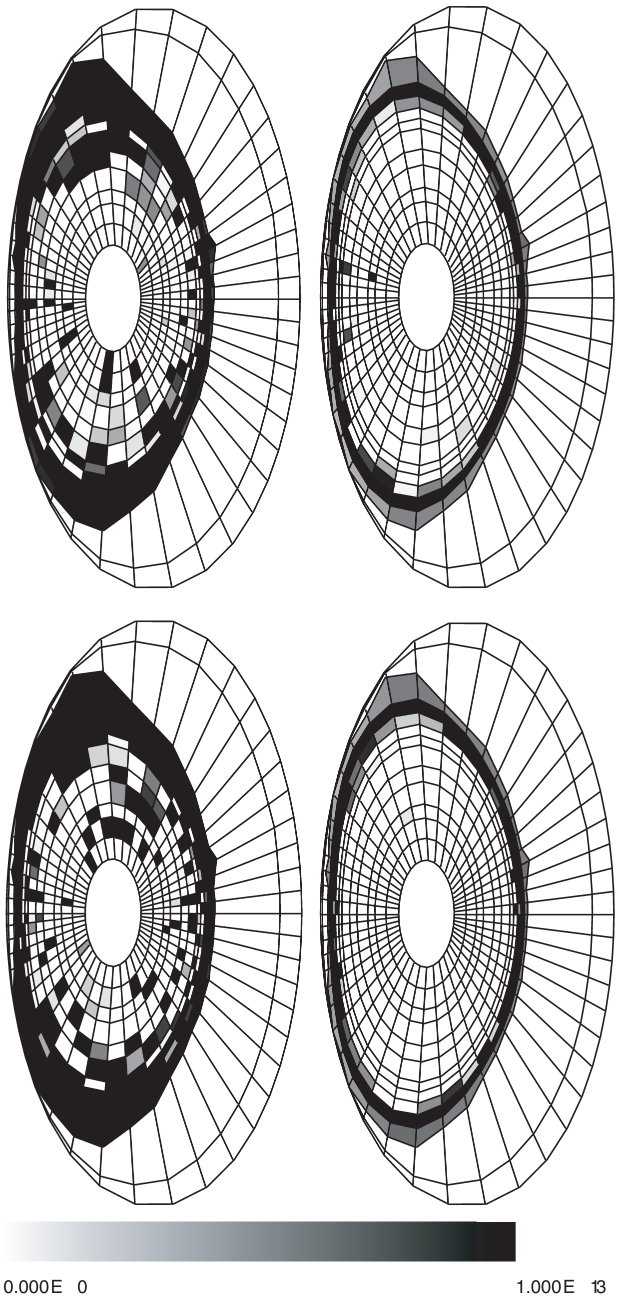

Fig. 3 H_α emission profile for CASE D (above) and E (below). Left figures are the emission profile from excited hydrogen atoms and right figures are those from dissociated molecules.

confirmed that the effect of fast atoms on neutral penetration can not be neglected. Though the spatial resolution of Fig. 3 is not sufficient, plasma density profile becomes broader with the formation of ETB (i.e. CASE E) and neutral penetration into plasma is inhibited. So emission profile of H_α especially from molecular hydrogen becomes narrow.

4. Summary

Neutral particle behavior in CHS was studied with the Monte Carlo simulations. Obtained results are summarized like the following.

- In the limiter plasma like in the CHS standard configuration, neutral particle density is strongly dependent on the extension of effective recycling region of limiter. This may be checked with data of neutral pressure gauge.
- In CHS edge plasma, H_α emission is mainly from atomic hydrogens deeply penetrating into core plasma. But contribution from molecular hydrogens can not be neglected around LCFS.
- With the formation of ETB, plasma density profile becomes broader and neutral penetration into plasma is inhibited. So emission profile of H_α especially from molecular hydrogens becomes narrow.

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