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Effects of varying stochastic layer on edge plasma and impurity transport in 3D EMC3-EIRENE simulations of LHD

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HIGHLIGHTS

- The edge plasma and carbon impurity transport in LHD is studied EMC3-EIRENE code.
- The impact of the magnetic field structure on plasma distribution is studied.
- The erosion of in- and out-board sides is asymmetric for diverse magnetic structures.
- The effect of the magnetic configuration on impurity transport is investigated.

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ABSTRACT

The transport properties of edge plasma and carbon impurity in the stochastic layer of the Large Helical Device (LHD) have been studied with the three-dimensional edge transport code EMC3-EIRENE. The recent development of computational meshes, which store the magnetic configurations, has been used to carry out the studies of the impact of the magnetic field structure on the edge plasma and impurity transport in the stochastic layer. The horizontal variation of the magnetic axis position (R_{ax}) from 3.60 m to 3.90 m leads to more open flux channels connecting to the divertor and thus a stronger particle exhaust on the target, which results in a higher erosion of divertor target. Furthermore, the outboard divertor target plates suffer from the stronger erosion compared to the inboard divertor target plates for R_{ax} = 3.90 m, which is in contrast to the case of R_{ax} = 3.60 m. It is also found that the stronger CIV line emission is obtained at the outboard X-point region when the magnetic axis location moves outwards horizontally.

1. Introduction

The edge impurity transport in the fusion devices is recognized as an important issue in the studies of impurity screening [1–3] and radiative divertor plasma [4,5]. The effective impurity screening can alleviate the radiation of impurities in the core region and improve the energy confinement and plasma performance in the fusion facilities [6]. The impurity radiation in the edge plasma can reduce the power load on divertor target and extend the lifetime of plasma facing components [7].

The plasma edge region of the Large Helical Device (LHD) exhibits the stochastic magnetic layer, which is consisted of the stochastic fields, remnant magnetic islands and edge surface layers [8]. The impurity transport in the plasma edge region of LHD shows a quite different behavior from that in tokamaks with axisymmetric magnetic configuration [1]. Due to the complex structure of the stochastic magnetic field in LHD, the three-dimensional (3D) edge transport code EMC3-EIRENE [9,10] has been employed for the modelling of the edge plasma and impurity transport in the stochastic layer [1,11–13].

In the previous work, the influences of the parallel force balance, impurity perpendicular diffusivity and the first wall in the modelling have been studied to constrain the uncertainty in the selection of free parameters of the impurity transport model in EMC3-EIRENE [12,13]. It is found that the deep penetration of impurity into the high plasma density region due to the enhanced perpendicular diffusivity and the first wall source causes the change of CIV impurity emission pattern as well as the absolute intensity.

In this work, the studies of the impact of the magnetic field structure on the edge plasma and impurity transport in the stochas-

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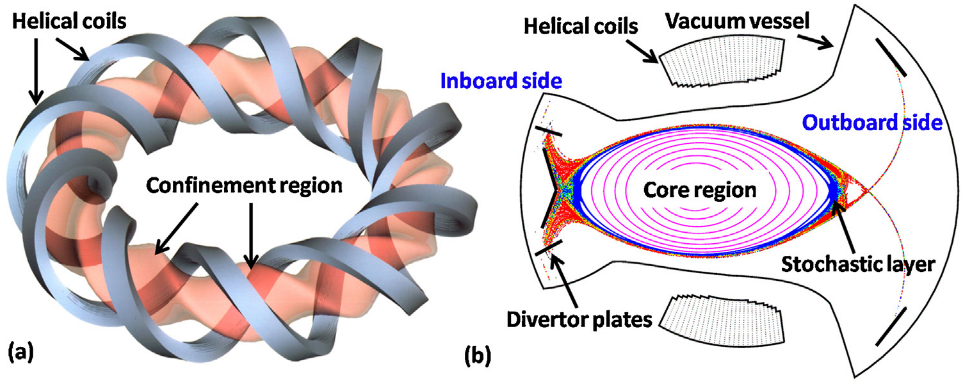

Fig. 1. Schematics of (a) the magnetic configuration in the confinement region and the helical coils and (b) the cross section of LHD at the toroidal angle of $\varphi = 18^{\circ}$.

tic layer of LHD have been conducted by EMC3-EIRENE modelling based on the recent development of the computational meshes. The LHD has very complicated magnetic geometry and engineering structure of first wall and divertor. In particular, the magnetic shear inside the divertor leg region of LHD is strong, which increases the difficulty to make the 3D computational mesh. The development of the computational mesh for the LHD divertor regions has been done in [11], which are used to treat the plasma and impurity transport in the divertor regions. Based on this improvement, three typical magnetic configurations (R_{ax} = 3.60 m, 3.75 m and 3.90 m, R_{ax} is magnetic axis location), which are commonly used in the LHD experiments, have been developed to check their effects on the edge plasma and impurity transport characteristics. The EMC3 code is applied to simulate the transport for the mass, momentum, ion and electron energy, which is coupled with the EIRENE code to handle the transport of neutral atoms and molecules. The impurity transport model is self-consistently implemented into the EMC3 code for the studies of the relevant impurities, which has been modeled by a fluid momentum balance equation. The feedback of impurities on the background plasma is addressed by the energy sinks induced by ionization and excitation of impurities. In Section 2, the edge magnetic configurations of LHD are introduced. The modelling results and discussion are presented in Section 3. Finally, a summary is given in Section 4.

2. Edge magnetic configuration of LHD

Fig. 1(a) shows the schematic of the LHD magnetic configuration in the confinement region and the helical coils. The magnetic field geometry of LHD is created by a pair of helical coils twisted with poloidal and toroidal pitch numbers of $l = 2$ and $n = 10$, respectively. Hence, the magnetic configuration possesses ten toroidal field periods. The position of the magnetic axis can be controlled by the additional vertical field coils. The plasma distributions at the poloidal cross sections of $\varphi = 0^{\circ}$, 18° and 36° in LHD have the up-down symmetry structures. Fig. 1(b) shows the poloidal cross section of LHD at the toroidal angle of $\varphi = 18^{\circ}$. The stochastic magnetic configuration is produced by the helical coils because of the overlapping of magnetic island chains. The divertor legs induced by the stretch of the flux tubes near X-points connect to the divertor targets as shown in Fig. 1(b). The divertor target plates are made of graphite, and vacuum vessel wall is made of stainless steel.

The magnetic field aligned grid is used by EMC3-EIRENE to provide computationally effective access to fast magnetic field reconstruction during the Monte-Carlo (MC) particle tracing [14,15]. This scheme intrinsically allows to treat non-regular field structures such as helical devices and non-axisymmetric tokamaks with resonant magnetic perturbation (RMP) fields. The EMC3-EIRENE code has been used to study the divertor particle and heat fluxes for ITER with the application of RMP fields [16]. For the edge magnetic configuration of LHD, the whole torus can be treated as one field period, i.e., $\varphi = 0–36^{\circ}(=360^{\circ}/10)$ under the assumption of a complete toroidal periodicity. Due to the property of the stellarator symmetry, the simulation domain could be reduced to the range of $\varphi = 0–18^{\circ}$. The physical quantities in the toroidal domain of $\varphi = 18–36^{\circ}$ could be obtained with the mapping relation of $f'(R', Z', \varphi') = f(R', -Z', 36 - \varphi')$, where f is physical quantity in the range of $\varphi = 0–18^{\circ}$, and f', R', Z', φ' are physical quantity and coordinates

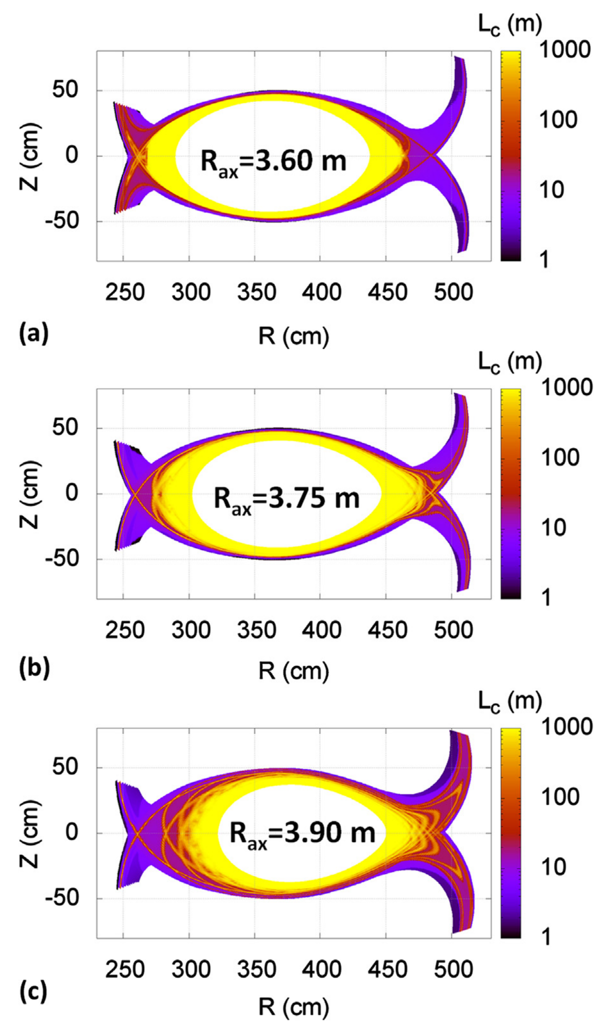

Fig. 2. Poloidal cross sections of the connection length distribution at the toroidal angle of $\varphi = 18^{\circ}$ for R_{ax} = 3.60 m (a), 3.75 m (b) and 3.90 m (c).

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