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Transport Simulations of Plasmas in Thailand Tokamak 1 and ITER with High Impurity Concentration Scenarios

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Understanding the effect of high impurity concentration in tokamaks is crucial for future tokamak operation such as ITER and DEMOs, since the impurity in tokamaks dilutes the fuels and reduces fusion power. This can also result in plasma instabilities and affects the overall performance of the machines. On the other hand, impurity radiation in SOL region could mediate the heat load to diverter. Thus, a thorough understanding and balancing the cons and pros of impurity transport would be of great interest. This lead to the goal of this work, which is a numerically study of the effect of high impurity concentration, especially for helium impurity, inside small tokamak, particularyThailand Tokamak-1 (TT-1) which is previously known as HT-6M tokamak, and large fusion reactor (ITER) by using the 1.5 BALDUR integrated predictive modeling code with fully predictive boundary models for densities and temperatures.
The BALDUR integrated predictive modelling code is a mathematical model which is designed to compute the time evolution of plasma profiles including electron and ion temperatures, deuterium and tritium densities, helium and impurity densities, neutrals, and fast ions [1, 2]. These time-evolving profiles are self-consistently determined in the BALDUR code by combining the effects of several physical processes, for example anomalous and turbulent transports, plasma heating, impurity accumulation, and sawtooth oscillations. The BALDUR simulations have been intensively validated against various plasma experiments and yielded an overall agreement of 10% deviation [1, 2]. In the BALDUR code, fusion-heating power is determined using the nuclear reaction rates and a Fokker Planck package to compute the slowing down spectrum of fast alpha particles on each flux surface in the plasma. The fusion-heating component of the BALDUR code also computes the rate of production of thermal helium ions and the rate of depletion of deuterium and tritium ions within the plasma core. In this work, two anomalous transport models (the multimode anomalous transport model and Mixed Bohm/gyro-Bohm model) in BALDUR will be used to carry out simulations of ITER. The neoclassical transport is carried out using NCLASS module [3].

In the present work, the boundary conditions for the densities of hydrogenic and impurity particles are determined based on an assumption that their pedestal densities are a large fraction of their line average densities. This idea allows us to write
n_(ped,hyd)=C_hyd n_(l,hyd) (1)

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n\_(ped,imp)=C\_imp n\_(l,imp),     (2)
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where n_(ped,hyd) and n_(ped,imp) are the pedestal densities of the hydrogenic and impurity particles, n_(l,hyd) and n_(l,imp) are the line average densities of the hydrogenic and impurity particles respectively. C_hyd and C_imp are the proportional constants whose values can be directly determined from experiments.

Figure 1 shows the plots between the deuterium and impurity (carbon) densities at the pedestal and their line average quantities. It can be noticed that the densities of both particle species correlate with the average values quite well and they have a strong linear relationship. By fitting the line average densities and the pedestal densities of the deuterium and carbon from 276 JET H-mode discharges [4], we found that the values of Chyd and Cimp equal 0.76 and 0.77 respectively. Note that the correlation coefficient (R2) between the pedestal densities and the line average values for deuterium and carbon are 0.96 and 0.88, respectively. Thus, in this work, the linear relations shown in equations (1) and (2) are used for estimating the density of all hydrogenic and impurity species at the top of the pedestal. It is worth noting that several other models for describing density at the top of the pedestal have similar characteristics, such as reference [5].

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We carry out the BALDUR code with fully predictive boundary model to investigate the effect of the impurity concentration on the behaviors of the tokamak plasmas in TT1 and ITER at the steady state. Here the amount of the helium concentration can be adjusted by varying the parameter in Cimp equation (2). For ITER plasma, we found that the transport simulations using the MMM95 model in the core and setting Cimp = 0.77 for the

concentration of impurities at the edge the yields the helium fraction (NHe / Ne) about 10%. By adjusting this parameter, it allows us to the vary the amount of the impurity in the core region.

Figure 2 shows the radial profiles of the electron, helium, and electron temperature as the helium fractions are changed from 0.002 % to 20%. We can see that the electron density and temperature slightly change at the low concentration of helium (below 5%). It is worth noting the halo profiles observed in the electron density is commonly occurred for the transport with the MMM95 model. However, the helium fraction increases more than 10%. There is strong inward velocity pinch and it causes the increasing amount of the electron density in the inner core region (r/a < 0.4). This also leads to the decrease of the electron temperature in the same region. Moreover, the large amount of the helium fraction significantly reduces the fusion power. As the helium fraction increases from very small amount (~0.002%) to large amount (~20%), the fusion power drops by a factor of 5. When the core transport with mixed Bohm/gyro-Bohm is used, the similar results can be obtained. The H-mode plasma may also transit to the L-mode plasma during the increase amount of the helium fraction.

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