Dependence of ITER Performance on Pedestal Temperature, Average Electron Density, Auxiliary Heating Power, and Impurity Content

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Abstract

Self-consistent modeling of ITER has been carried out using the 1.5D BALDUR integrated predictive modeling code. In these simulations, a core transport model is described by a combination of an anomalous transport and a neoclassical transport. An anomalous transport is calculated using the Multimode (MMM95) core transport model, while a neoclassical transport is computed using the NCLASS model. At the reference design point, it is found that ITER fusion power production improves with the increase of pedestal temperature, average electron density, and auxiliary heating power. However, the power production reduces with the increase of impurity content. For the variation of the density and auxiliary heating power, the fusion Q increases linearly with both parameters. It is also found that the sawtooth mixing radius tends to decreases with increasing of pedestal temperature, average electron density and auxiliary heating power; however, it increases with impurity content. In addition, the sawtooth frequency tends to increase with the increase of heating power; but decrease with pedestal temperature.

Introduction

The concept of magnetic confinement fusion (MCF) has long been explored to address the feasibility of nuclear fusion energy. The ITER project [1] is an international collaboration to investigate the scientific and technological feasibility of MCF. Producing fusion reactions which satisfy such a condition inside a tokamak requires our ability to both heat and contain high-temperature plasmas. Comprehensive computer simulations are needed to optimize to plasma conditions before actual experiments are carried on.

In this study, the BALDUR integrated predictive modelling code [2] is used to carry out simulations of plasmas with the standard *H*-mode (high confinement) scenario, as it is the reference scenario for ITER. Multi-Mode (MMM95) anomalous core transport model [3] is utilized for the core region to describe the effects of turbulence. In addition, the neoclassical transport calculated using NCLASS module [4] is combined with the anomalous core transport to describe the core transport. The effect of sawtooth oscillation is also included, where a Porcelli sawtooth model [5] is used to determine a sawtooth crash and a modified Kadomtsev magnetic reconnection model [6] is used to describe the effects of sawtooth crash.

Results and Discussions

The BALDUR integrated predictive transport modeling code is used to carry out the simulations of ITER with the designed parameters (R = 6.2 m, a = 2.0 m, I_p = 15 MA, B_T = 5.3 T, κ_{95} = 1.85, δ_{95} = 0.33 and n_l = 1.0x10^{20} m^{-3}). In this work, the plasma parameters are ramped up to the target values within 15 sec. It is found that the plasma reaches the H-mode phase at the time of 4 sec. It is worth noting that even though the plasma current reaches its flat top with in 15 sec, complex interactions within the plasma itself ─ such as the self plasma heating by the alpha particle and redistribution of heating power after sawtooth crash ─ still occurs and lead to interesting observation. Note that the sawtooth oscillation is considered during the time of 15 sec to 597 sec. The boundary conditions are provided at the top of the pedestal by the pedestal model described above. It is assumed that the electron and ion pedestal temperatures are of the same values. In most simulations, the auxiliary heating power of 40 MW, which includes only RF heating power, is used.

The effects of pedestal temperature on the temperature and density in ITER are shown in the Figure 1. In each panel, the central and average profiles are shown. It is worth noting that in this work, the ion pedestal temperature is set to be the same as the electron temperature. The pedestal temperature, which is the boundary conditions in the simulation using BALDUR code, is varied from 2 keV to 8 keV. It can be seen that as the pedestal increases, the central and average temperatures are increase for both electron and ion until the pedestal temperature of 8 keV. The central and average temperatures drop after pedestal temperature of 8 keV. For the electron density, both central and average density drops as the pedestal temperature increases.

Figure 2 show the sensitivity of nuclear fusion performance on pedestal temperature, average electron density, auxiliary heating power, and impurity content. Note that the nuclear fusion performance is described in term of fusion Q $\left(= \frac{5 \times \text{alpha heating power}}{\text{auxillary heating power}} \right)$. It is found that the nuclear fusion performance increases rapidly with increasing of pedestal temperature until the pedestal temperature of 8 keV. This trend of nuclear fusion performance can be explained by the behavior of central temperature and density, which tend to decrease when the pedestal temperature is more than 8 keV. It can be also seen than the performance increase linearly with average electron density. However, the performance decreases when the auxiliary heating power or impurity content increases.

The effect of pedestal temperature, average electron density, auxiliary heating power, and impurity content (Z_{eff}) variations on sawtooth oscillation is also investigated. Note that in all simulations, the sawtooth oscillation is considered after 15 sec until 597 sec. The sawtooth frequency and sawtooth mixing radius are averaged during last 30 sec of each simulation. It is found that the sawtooth frequency ranges from 0.2 Hz to 0.5 Hz and the sawtooth mixing radius ranges from 0.8 m to 1.1 m. The sawtooth mixing radius tends to decreases with increasing of pedestal temperature, average electron density and auxiliary heating power; however, it increases with impurity content. In addition, the sawtooth frequency tends to increase with the increase of heating power; but decrease with pedestal temperature.

Conclusions

Self-consistent modeling of ITER has been carried out using BALDUR integrated code. At the reference design point, it is found that ITER fusion power production improves with the increase of pedestal temperature, average electron density, and auxiliary heating power. However, the power production reduces with the increase of impurity content. For the variation of the density and auxiliary heating power, the fusion Q increases linearly with both parameters. It is also found that the sawtooth mixing radius tends to decrease with increasing pedestal temperature, average electron density and auxiliary heating power; however, it increases with impurity content. In addition, the sawtooth frequency tends to increase with the increase of heating power; but decrease with pedestal temperature.

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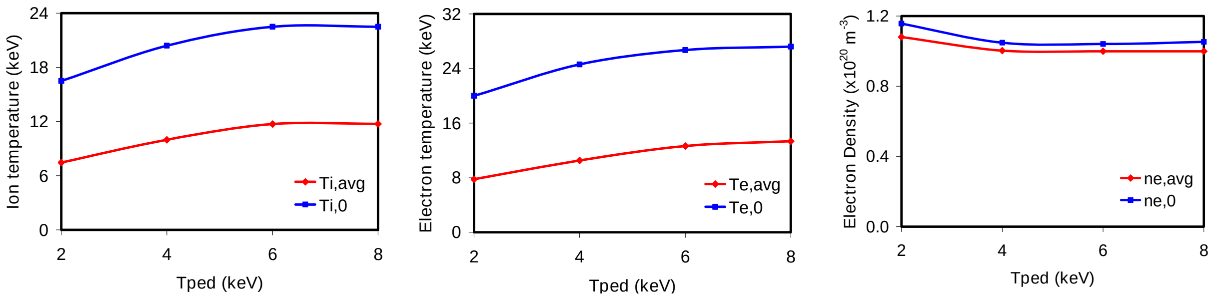

Figure 1: The ion temperature (left), the electron temperature (middle) and the electron density (right) are shown for ITER at the time of 300 sec.

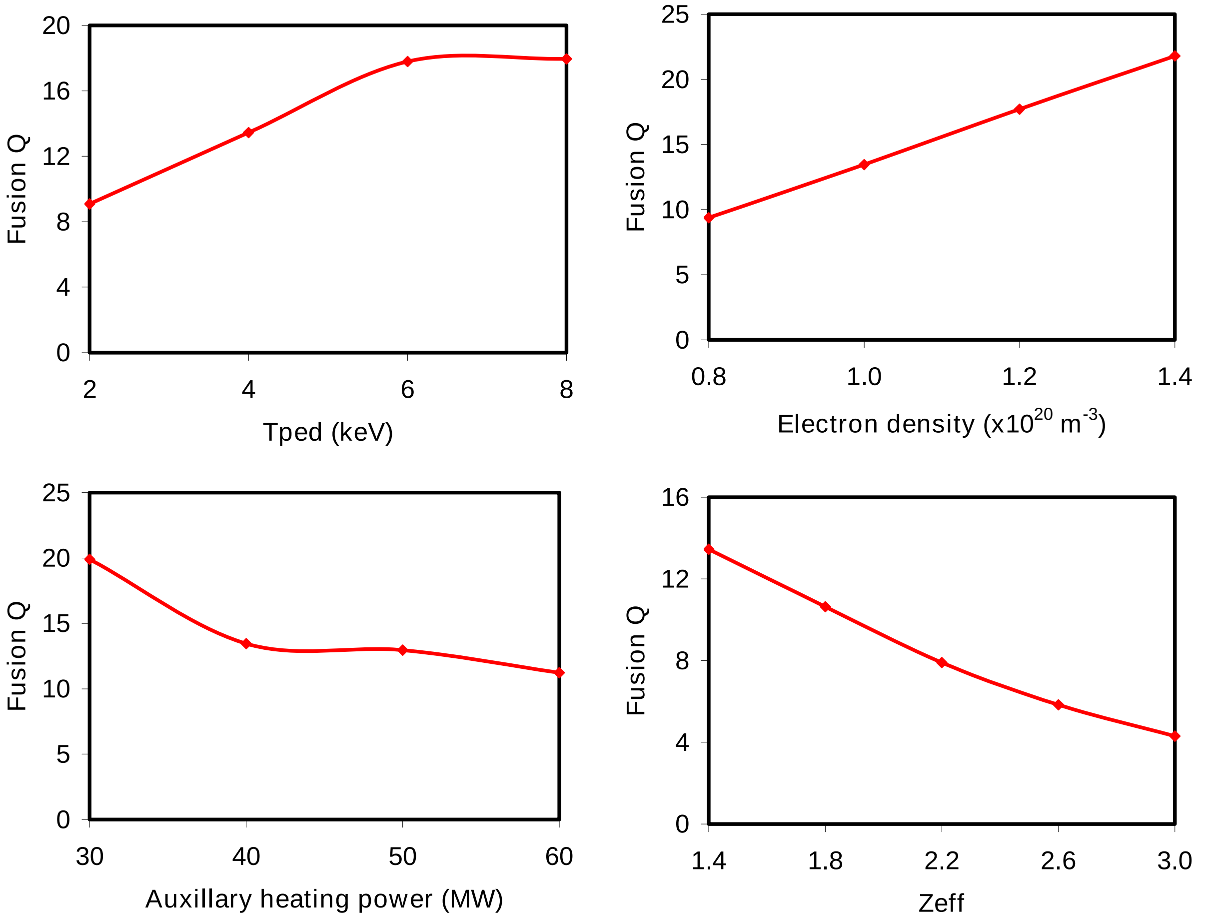

Figure 2: The sensitivity of fusion Q on pedestal temperature (top left), average electron density (top right), auxiliary heating power (bottom left), and impurity content (bottom right) are shown.