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Numerical simulation of fuel isotope transport during DEMO start-up phase

K. Miyamae[1], H. Yamada[1], A. Fukuyama[2].
[1] Graduate school of Frontier Sciences, The University of Tokyo, [2]Kyoto University.
e-mail (speaker): miyamae.kento22@ae.k.u-tokyo.ac.jp

This study has investigated the effect of particle transport of fuel ions (deuterium (D) and tritium (T)) and helium ash (He) as well as their heat transport on the nuclear fusion output in a DEMO reactor. The result was assessed and possible start-up scenarios for DEMO is discussed.

While development of a reliable startup scenario for DEMO that aligns with physical design and engineering constraints is important, it still remains in research with many different assumptions over the plasma physics. In particular, particle control is an open issue because of immature physics understanding and insufficient technological readiness for that . Establishment of a fueling and exhaust scheme is inevitable for both stable burning control and efficient self sufficiency of T fuel in a fusion plant.

In this study, the hydrogen isotope effect in D/H/He mixture plasmas on transport and resultant fusion power output has been discussed with the integrated tokamak modeling code TASK/TR [1]. TASK/TR solves one-dimensional transport equations for densities, temperatures, and a poloidal magnetic flux. Thermal diffusivity and particle diffusivity is calculated as sum of neoclassical transport and drift wave transport. For drift wave transport, the CDBM (Current diffusive ballooning mode) model is incorporated. Thermal diffusivity of CDBM is expressed as below equation.

$$\chi_{\mathrm{CDBM}} = CF\,(s,\alpha)\alpha^{3/2}\frac{c^2}{\omega_{\mathrm{pe}}^2}\frac{v_{\mathrm{A}}}{qR}$$

$$D_{\mathrm{CDBM}} = K * \chi_{\mathrm{CDBM}}$$

c is the velocity of light, ω_{pe} is the electron plasma frequency, v_A is the toroidal Alfvén velocity and q is the safety factor. Factor F is a function of the magnetic shear s and the normalized MHD pressure gradient α. K is constant factor derived from experimental results.

Fusion reactor parameters and reference operational sequences are based upon the recent tokamak fusion DEMO design by the Joint Special Design Team [3].

The result of fusion power development and plasma current for reference case is shown in Fig. 1. Also, density profile at t=1,000 s is shown in Fig. 2 (a). The result suggests that with consideration of particle transport, efficient fueling of D and T to the core region is difficult in particular in the start-up phase without anomalous inward pinch. Together with the buildup of He, fuel ions show hollow density profiles, which hinders higher fusion output. The fusion output was decreased by about 70% compared to reference scenario with fixed electron and fuel ion density profile.

The density profile of deuterium and tritium with isotope effect incorporated model is shown in Fig. 2 (b). To incorporate isotope effect as mass dependencies, χ_{CDBM} for each ion is calculated separately, where Alfvén velocity differs for each ion species due to ion mass. Due to the isotope effect, heavier ions have less diffusivity, resulting in the difference of density profiles. Although He ash built up more and ratio of deuterium density and tritium density deviated from 1:1, its effect to the fusion power output was relatively small (less than 5%).

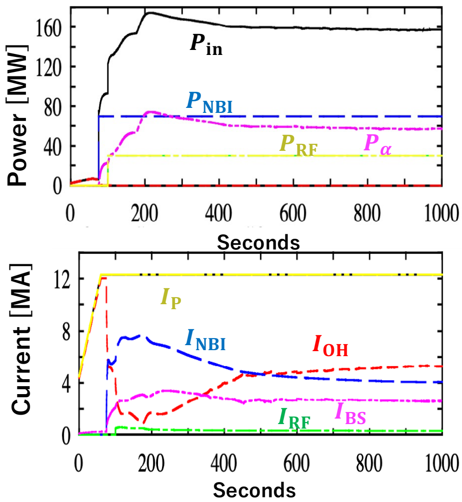

Figure 1 Temporal evolution of plasma current and fusion output in the base case scenario.

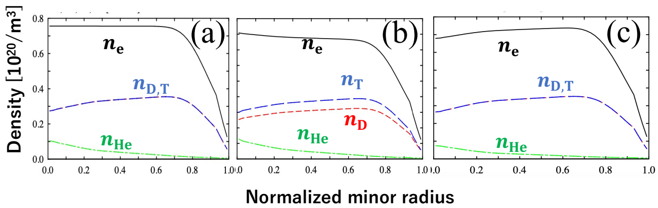

Figure 2 Density profile of ions and electron in (a) the base case scenario, (b) the case with isotope effect of CDBM integrated , and (c) He enhancement effect incorporated model.

To discuss the effect of He build up, arbitrary enhancement of He particle transport is integrated to the diffusion model as bellow equation.

$$D_{\mathrm{He}} = A * (D_{\mathrm{NC}} + D_{\mathrm{DW}})$$

A denotes arbitrary constant coefficient expressing the enhancement of particle transport. The density profile with He particle diffusivity enhancement effect incorporated model is shown in Fig. 2 (c). When enhancement factor A is set to 1.5, He build up is mitigated to about 2/3 in the core region. The mitigation also made possible to increase fueling when considering electron density limit.

References

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