Transport Simulation in LHD Plasmas Using Gyro-Bohm Transport Models Including the Effect of Temperature Gradient

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1. Introduction

The integrated transport simulation that self-consistently combines a variety of physical models describing the phenomena with different time scales is essential for a systematical elucidation of the confinement physics in toroidal plasmas. TASK3D[1] is an integrated transport simulation code for the helical plasmas based on TASK[2] which is applicable for 2D tokamak configurations. It is under development in collaboration with Kyoto University and NIFS and has been used to analyze a variety of LHD experiments so far. Using TASK3D, we have performed self-consistent calculation of the heat transport and heating profile for parameters in experiments (Experimental analysis) and predictive simulations assuming a variety of NBI heating conditions (Predictive analysis). Last year, we have performed a series of experiments to validate the simulation results of TASK3D. In this study, in order to improve the accuracy of the turbulent transport model in TASK3D, we have made comparison and the validation of gyro-Bohm based transport models with LHD experimental results (14th, Sep. 2011, EXP No. #773).

2. Integrated simulation code, TASK3D

TASK3D has a modular structure and each module describes different physics phenomena. Figure 1 shows the flow diagrams of the 1D heat transport simulation using TASK3D. Here, TR is the 1D diffusive transport module, and solves particle transport equation, heat transport equation, and magnetic field equation. In this study, we only solve the heat transport equation and the density and magnetic field are fixed. The neoclassical transport coefficients are calculated by the neoclassical transport database, DGN/LHD[3], and the radial electric field is calculated by the ER module, according to the ambipolar condition. The equilibrium magnetic field is calculated by the VMEC code, and heat sources can be calculated by the FIT3D, WR, and WM modules corresponding to NBI, ECH, and ICH, respectively. In this study, we only connect the FIT3D module and consider the NBI heated plasmas. The NBI power deposition profiles are calculated in response to changes in the spatial profiles of temperature and density calculated by the TR module. Thus, we can perform self-consistent simulations of heat transport in NBI plasmas.

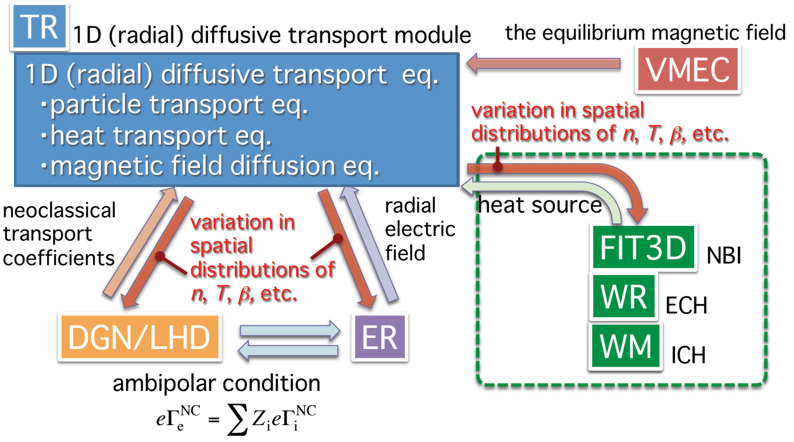

Fig. 1. The flow diagrams of 1D heat transport simulation using TASK3D

3. Simple gyro-Bohm transport model

We assume that the thermal diffusion coefficients are given by the sum of a turbulent term - χ^{TB} and a neoclassical term χ^{NC}, $\chi = \chi^{TB} + \chi^{NC}$. Only the neoclassical components of the particle diffusion coefficient, heat pinch velocity, and particle pinch velocity are considered. Neoclassical transport coefficients are accurately evaluated by using the neoclassical transport database, DGN/LHD. To handle turbulent transport, we introduce several transport models. First we assume $\chi_e^{TB}=\chi_i^{TB}$ and adopted a simple gyro-Bohm model, $\chi^{TB}_{\mathrm{gyroBohm}} = \mathrm{C}_{\mathrm{gyroBohm}}\left(T/eB\right)\left(\rho_i/a\right)$ compatible with International Stellarator Scaling 95, ISS95[4]. Here, $\mathrm{C}_{\mathrm{gyroBohm}}$ is a constant factor, which is adjusted so that the simulation results well reproduce experimental observations.

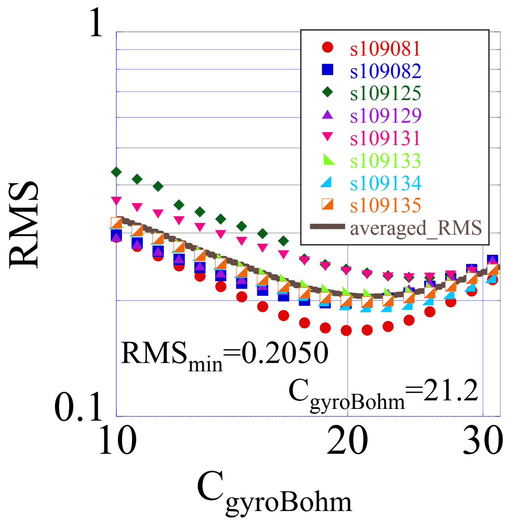

Fig. 2. Optimization of $\mathrm{C}_{\mathrm{gyroBohm}}$

In order to determine $\mathrm{C}_{\mathrm{gyroBohm}}$, we simulate the reference shots (s109081, s109082, s109125, s109129, s109131, s109133, s109134, s109135, 14th, Sep. 2011, EXP No. #773). The characteristics of these shots are R_{axis} = 3.6m, B_0 = 2.75-2.85 T and relatively high T_{i} plasmas. In this study, LHD experimental data is used for initial profiles of the simulation; density profiles are fixed to the experimental values; electron and ion temperature profiles are calculated until the stationary state is obtained; initial MHD equilibrium is calculated by the VMEC code; the radial electric field E_{r} is determined by the ambipolar condition with the experimentally obtained density and temperature profiles. Calculating the RMS values of the temperature profile, $\mathrm{RMS}=\sqrt{\dfrac{1}{\mathrm{NRMAX}}\sum_{\mathrm{NRMAX}}\left(\dfrac{T^{\mathrm{TASK3D}}(\rho)-T^{\mathrm{EXP}}(\rho)}{T^{\mathrm{EXP}}(\rho)}\right)^2}$, and using the various values of $\mathrm{C}_{\mathrm{gyroBohm}}$ in reference shots, we found that the $\mathrm{C}_{\mathrm{gyroBohm}}$ that minimizes the average value of RMS is 21.2, as shown in Figure 2. In this case, the averaged RMS is about 20%. Using this value of $\mathrm{C}_{\mathrm{gyroBohm}}$, we have performed predictive heat transport simulation in LHD as shown Fig. 3(a). In order to validate the simulation results, the LHD experiments in the similar NBI heating condition and density profiles to the TASK3D simulation were performed as shown Fig. 3(b). T_{e} obtained by the predictive simulation is in good agreement with the experimental results, while T_{i} obtained by the predictive simulation is about 25% lower then the experimental results in the core region. In recent high T_{i} LHD experiments, the T_{i} profiles obtained by TASK3D with this simple gyro-Bohm model are also rather low in the plasma core region.

4. Extended gyro-Bohm model

In order to improve the reproducibility, we consider the effect of the temperature gradient on the heat transport and include the temperature gradient factor, $a\,\nabla T/T$, in the gyro-Bohm model as $\chi^{\mathrm{TB}}_{\text{gyro-Bohm}_{\text{x}}\text{grad}T}$ = $\mathrm{C}_{\text{gyro-Bohmxgrad}T}(T/eB)(\rho/a)(a\,\nabla T/T)^{\mu}$, where μ is the index to measure the effect of the ∇T in turbulence transport. We find that in the case of μ=1.5, the RMS value is the smallest. Thus, we extend the gyro-Bohm model as

$$\chi_{\mathrm{e}}=\mathrm{C}_{\mathrm{e}}^{(0)}\frac{1}{16}\frac{T_{\mathrm{e}}}{eB}\frac{\rho_i}{a}+\mathrm{C}_{\mathrm{e}}^{(1.5)}\frac{1}{16}\frac{T_{\mathrm{i}}}{eB}\frac{\rho_i}{a}\left(\frac{\nabla T_{\mathrm{i}}}{T_{\mathrm{i}}}a\right)^{\frac{3}{2}},\quad \chi_{\mathrm{i}}=\mathrm{C}_{\mathrm{i}}^{(1.5)}\frac{1}{16}\frac{T_{\mathrm{i}}}{eB}\frac{\rho_i}{a}\left(\frac{\nabla T_{\mathrm{i}}}{T_{\mathrm{i}}}a\right)^{\frac{3}{2}}.$$

Figure 4 shows the TASK3D simulation results with the extend gyro-Bohm model above. By adopting the effect of ∇T, TASK3D simulation well reproduced both the electron and ion temperatures for the LHD plasmas.

5. Summary

We have been developing the integrated simulation code TASK3D for non-axisymmetric plasmas. We have chosen the constant factor for a simple gyro-Bohm transport model, $C_{\text{gyro-Bohm}}$, using the recent LHD experimental results. With this $C_{\text{gyro-Bohm}}$, we have performed a predictive simulation and found that the predicated T_e is in good agreement with the experimental results, while the predicted T_i is less peaked compared with the experimentally observed profile. In order to improve the ion temperature profile, we have introduced an extended gyro-Bohm model including the temperature gradient factor, $a\nabla T/T$. With this transport model, TASK3D simulation well reproduced both the electron and ion temperatures in a series of shots of the LHD plasmas.

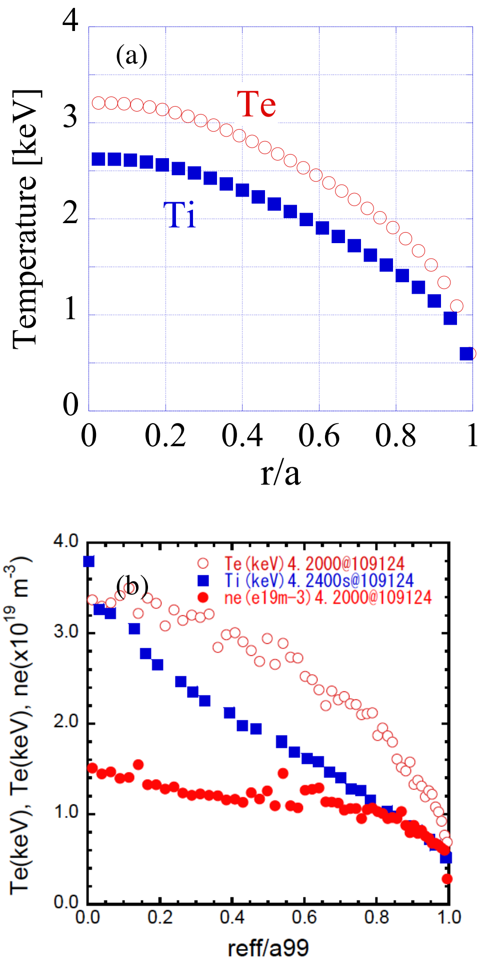

Fig. 3. (a) Rsults of Predictive simulation by TASK3D and (b) Experimental results under close condition with TASK3D simulation.

Acknowledgments

This work is supported in part by Grant-in-Aid for Scientific Research (S) (20226017) from JSPS and by the NIFS Collaboration Research program.

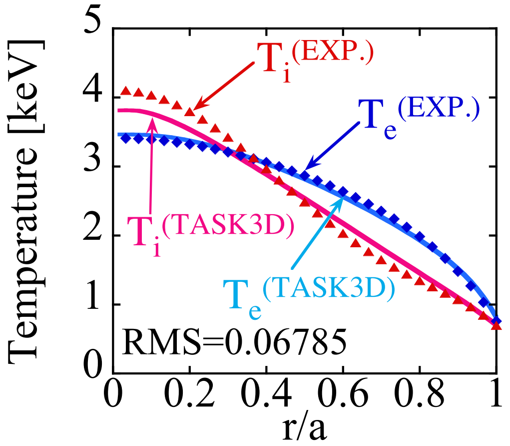

Fig. 4. Comparison of TASK3D simulation results with extended gyro-Bohm model with experimental results.

References

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