MF-I3 AAPPS-DPP2019

3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Simulations of radial electric field and divertor heat flux width using the BOUT++ transport code with drifts

Nami Li[1,2], X.Q. Xu[2], Zeyu Li[2,3], J.W. Hughes[4], J.L. Terry[4], J.Z. Sun[1], and D.Z. Wang[1]
[1] School of Physics, Dalian University of Technology, China
[2] Lawrence Livermore National Laboratory, USA
[3]School of Physics, Peking University, China
[3]MIT Plasma Science and Fusion Center, USA
e-mail (speaker): linami@mail.dlut.edu.cn

The BOUT++ fluid transport code has been developed with all cross-field drifts and sheath boundary conditions in the scrape-off-layer (SOL). The radial electric field (Er) is calculated by coupling a plasma transport model with the quasi-neutrality constraint in a vorticity equation. Based on the experimentally measured plasma density and temperature profiles in Alcator C-Mod discharges, the effective radial particle and heat diffusivities are inferred from the set of measured plasma profiles inside the magnetic separatrix using transport equations. The sheath boundary conditions act to generate a large and positive Er in the SOL, which is consistent with experimental measurements. The effect of magnetic particle drifts is shown to play a significant role on local particle transport and the radial electric field [1]. The net particle flow due to the magnetic drifts causes the charge separation in both the edge and SOL regions, yielding large modification of the Er across the separatrix. The calculated steady state Er has been compared with experimental measurements from a C-Mod discharge using charge exchange recombination spectroscopy.

The steady state solutions of divertor heat flux width for both ions and electrons have been investigated for C-Mod and CFETR. The results have been compared with experimental measurements from C-Mod EDA H-mode discharges using the IR camera, probe and surface thermocouple. Four C-Mod discharges with lower single null divertor configuration are simulated. A turbulence diffusivity scan ($\chi_\perp$) identifies two distinct regimes: a drift dominant regime when $\chi_\perp$ is small; a turbulence dominant regime when $\chi_\perp$ is large, as shown in Figure 1. The Goldston heuristic drift model yields a lower limit of the width λ_q. These studies indicate that drifts and turbulent transport compete to determine the heat flux width in C-Mod EDA H-mode discharges [2]. The transition from a drift dominant regime to a turbulence dominant regime is determined by the critical value of thermal diffusivity $\chi_\perp^c$, which depends on two factors: machine parameters, such as size, and plasma operating regime. From C-Mod to CFETR and ITER, the critical value of thermal diffusivity $\chi_\perp^c$ is significantly reduced, because of the larger machine sizes, stronger magnetic field and higher current, which reduces the contributions of the drift-based radial transport. BOUT++ simulations for ITER and CFETR plasmas in the ELMy H-mode regime indicate that both ITER and CFETR will possibly be in a turbulence dominant regime and divertor heat flux width λ_q no longer follows the $1/B_{pol,MP}$ experimental Eich scaling [3, 4].

A new coupling model has been developed to integrate multi-scale turbulence and transport simulations, including processes such as ELM bursts and pedestal recovery. Good agreement has been achieved between solutions obtained by coupled simulation and those obtained by direct simulation of the unseparated equations. Multiple ELM cycles have been simulated using the coupling technique in circular geometry.

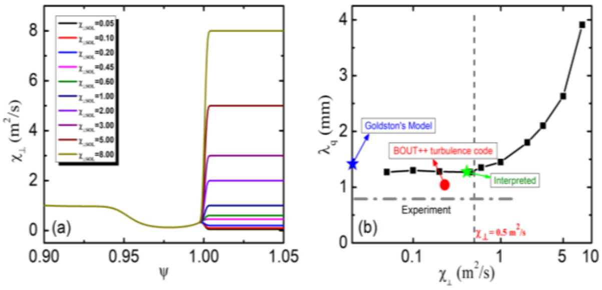

Figure 1 (a) Radial profiles of heat diffusivity $\chi_\perp$. The SOL $\chi_\perp$ are increased in simulations 160 times from 0.05 m2/s to 8 m2/s (b) divertor heat flux width vs. the SOL heat diffusivity $\chi_\perp$. The blue star is the width calculated from Goldston's model, which assumes small $\chi_\perp$. The red bullet is calculated from BOUT++ turbulence code and the green star is value of the heat flux scan at the experimentally interpreted value of $\chi_\perp$. The gray dashed dot horizontal line shows the experimental value. The vertical line shows the critical $\chi_\perp = 5m^2/s$ for the transition from drift dominant regime to turbulent dominant regime.

References

[1] N.M. Li, X.Q. Xu et al., Computer Physics Communications 228 (2018) 69–82

[2] N.M. Li, X.Q. Xu et at., "Simulations of divertor heat flux widths by using BOUT++ transport code with cross-field drifts", submitted to Nuclear Fusion, under review

[3] X.Q. Xu, N.M. Li et al., submitted to Nuclear Fusion, under review

[4] Ze-Yu Li, X.Q. Xu et al., Nuclear Fusion 59, 046014 (2019)