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High-accuracy simulations of SOL plasmas over a range of collisionality by a plasma fluid model based on the anisotropic ion pressure

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In a tokamak DEMO reactor, the scrape-off layer (SOL) heat flux will be enormously huge. It is indispensable to reduce the divertor heat load by the remote radiative cooling and plasma detachment [1, 2]. In order to find the effective heat control method, numerical simulation studies have widely been carried out. Conventional integrated simulation models for SOL-divertor plasmas adopt mainly the Braginskii's fluid model [3] to describe the fuel plasmas within a realistic computational cost, but the disagreement with experimental results still remains so far. A highly accurate simulation model of SOL-divertor plasmas needs to be developed in the category of plasma fluid models.

In fusion reactors such as DEMO, the plasma collisionality at the upstream of SOL is thought to be marginal [4]. To deal with such low-collisionality plasmas, incorporating proper kinetic factors (e.g. the heat-flux limiters and the parallel-ion-viscosity limiter) within the Braginskii's plasma fluid model is known to be important [5]. It is also reported from kinetic simulations based on a Particle-in-Cell (PIC) model that, when the plasma collisionality is marginal the ion temperature anisotropy becomes remarkable ($T_{\mathrm{i}\|}/T_{\mathrm{i}\perp}$ = 0.2~0.3 in which $T_{\mathrm{i}\|}$ and $T_{\mathrm{i}\perp}$ denote the parallel and perpendicular ion temperature, respectively) [5, 6]. Therefore, it is necessary to deal with the anisotropic ion temperature (or pressure) directly in simulating low-collisionality SOL-divertor plasmas of DEMO.

We have been developing a plasma fluid model based on the anisotropic ion pressure (AIP) named AIP model [7, 8]. By directly introducing AIP into a plasma fluid model, the parallel ion viscosity, which originates from the ion pressure anisotropy, is more accurately computed. This would contribute to better prediction of the parallel ion flow profiles. Instead, two closure models of the ion conductive heat fluxes are individually necessary for the transport equations of the parallel and perpendicular components of ion energy. At present, we incorporate heat-flux limited, Spitzer-Härm-like parallel conductive heat flux models.

In this study, the simulation results of AIP model are directly compared with those of a 1D3V PIC model named PIXY [9] over a range of collisionality to demonstrate the accuracy of AIP model. An ASDEX Upgrade-like 1D SOL-divertor system with a homogeneous magnetic field with the pitch B_t/B_p = 4 is used. It has a 4 m poloidal length between the divertor plates at the both ends with a 2 m homogeneous and isotropic particle/heat source region at the center. No neutrals and impurities are considered in the present simulations. In PIXY, the Coulomb collisions are directly simulated by the binary-collision model [10] while proper collision times are incorporated in AIP model [7]. It is shown that both a collisionless plasma ($L_\|/\lambda_{\mathrm{ii}} \sim 0.03$ and $T_{\mathrm{i}\|}/T_{\mathrm{i}\perp} \sim 0.15$ at the source-free region in which $L_\|$ and λ_{ii} represent the parallel connection length and the mean-free-path of the ion-ion Coulomb collisions, respectively) and a collisional plasma ($L_\|/\lambda_{\mathrm{ii}} \sim 20$ and $T_{\mathrm{i}\|}/T_{\mathrm{i}\perp} \sim 0.5$ at the source-free region) can be quantitatively reproduced by AIP model with a fixed set of the heat-flux-limiting coefficients. Also shown is that the Bohm criterion is automatically satisfied and the sheath heat transmission factors can be adjusted by the virtual-divertor model incorporated within AIP model [8]. These results indicate that an accurate enough simulation model of SOL-divertor plasmas can be developed in the category of plasma fluid models by incorporating AIP avoiding a direct use of computationally heavy, first-principle models. In the presentation, we will also discuss the difference in the behavior of the conductive heat fluxes in PIXY and AIP model.

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References

[1] N. Asakura *et al.*, Nucl. Fusion **57** (2017) 126050.
[2] N. Asakura *et al.*, Nucl. Mater. Energy **26** (2021) 100864.
[3] S.I. Braginskii, Rev. Plasma Phys. **1** (1965) 205.
[4] Y. Homma, Plasma Phys. Control. Fusion **64** (2022) 045020.
[5] A. Froese *et al.*, Plasma Fusion Res. **5** (2010) S1017.
[6] T. Takizuka *et al.*, J. Nucl. Mater. **128-129** (1984) 104.
[7] S. Togo *et al.*, Nucl. Fusion **59** (2019) 076041.
[8] S. Togo *et al.*, J. Comput. Phys. **310** (2016) 109.
[9] K. Ibano *et al.*, Nucl. Fusion **59** (2019) 076001.
[10] T. Takizuka and H. Abe, J. Comput. Phys. **25** (1977) 205.