19PB-071

Kinetic Dynamics Simulation of Plasma Detachment Process

T. Pianpanit[a], S. Ishiguro[a,b], H. Hasegawa[a,b], and R. Kanno[a,b]

[a] *The Graduate University for Advanced Studies (Sokendai), 322-6 Oroshi-cho, Toki 509-5292, Japan*
[b] *National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan*

The detached plasma has been proposed to reduce the heat flux to the divertor inside the fusion devices. The one- and two dimensional fluid code has been widely used to investigate the detached plasma. However, the cooling of plasma, trapped particle effects, and other kinetic dynamics in the detached plasma has not been well understood. Particle-in-Cell (PIC) simulation with Monte Carlo collisions is carried out to study dynamical kinetic behavior of the plasma, which are spatial and velocity space distributions of charged particles, self-consistent potential structure. Only the atomic processes of excitation, ionization and charge exchange are included in present work. The simulation has been performed by assuming the uniform neutral gas density in front of the divertor plate. The results show the decrease in plasma temperature and increase in plasma density inside the neutral gas region.

1. Introduction

Detached plasma [1] has been proposed as an effective way to reduce the divertor heat load. Atomic processes play a crucial role in the detached plasma. In the experiment, the detached plasma occurs when there is a high recycling rate near the divertor plate. This high recycling rate divertor increases the ion-neutral collision rate and decreases the plasma temperature. Neutral gas puffing can also increase the neutral density near the divertor and cause the plasma temperature to decrease. Sometimes the impurity is injected for the radiative loss.

Most of the detached plasma simulations are carried out by fluid code. Some of the simulation results show that the detachment front is not stable. It can move toward the X-point and cool down the main plasma [2]. This mechanism has not been well understood. The kinetic model may be able to understand this mechanism and help finding the solution of stable detached plasma.

Since the fluid model is derived base on the Maxwellian distribution and can be inadequate near the divertor plate [3]. In our present work, we aim to simulate the scrape-off layer (SOL) plasma near the divertor plate or in the divertor leg region by using the Particle-in-cell (PIC) simulation.

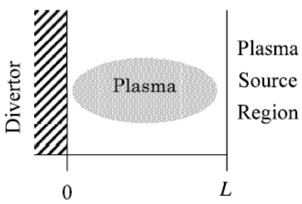

Fig.1. The configuration of the system.

2. Numerical Methods

This simulation composes of 2 parts, PIC and Monte Carlo collision (MCC). PIC simulation solves the equation of motion for individual particle inside the plasma and finds electric field generate by these particles. MCC simulation is necessary for the atomic processes that occur inside the plasma, such as charge exchange, ionization and impurity radiation. The physical process from gas puffing can also be applied by the MCC.

For the simulation system, we assume the right hand side of the system is the particle source and the left hand side is the divertor plate. The source of particle is assumed to be the half-Maxwellian distribution plasma. For the divertor, it can absorb the charge and normally becomes net negative surface charge. The system boundary is shown in Fig. 1.

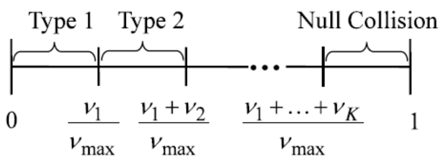

Fig.2. Collision probability for selecting the collision type in null collision method [4].

For MCC simulation, the null collision method has been used [2]. In null collision method, the maximum collision probability is calculated rather than calculating every particle collision probabilities. So the maximum probability that the particle will collide is

$$P_{\text{null}} = 1 - \exp\left[-\max_{\mathbf{x},v}(n_n \sigma_T v)\Delta t \right], \qquad (1)$$

where n_n is the density of neutral particle. σ_T is the total cross section of the atomic processes of each species. v is the velocity of each particle and Δt is time interval of each time step. This probability will define the number of particle that will collide in each time step then the collision type will be select for each particle as in Fig. 2, where $\nu = n_n \sigma v$ is the collision frequency.

The collision processes that are included in this simulation are elastic collision, charge exchange, ionization and excitation.

3. Simulation Results

The simulation is carried out with the system parameters as in Table I. The neutral gas box is stay in the left hand side of the system with the width of the box equal to 0.1 m. The neutral gas density is assumed to be uniform and constant in time and the neutral gas density $n_{n0} = 3.2\times10^{18}$ m^{-3}.

The results are given in Fig. 4. They show the decrease in ion temperature and the increase in plasma density inside the neutral gas box. Most of the energy loss is caused by ion elastic collision and charge exchange process.

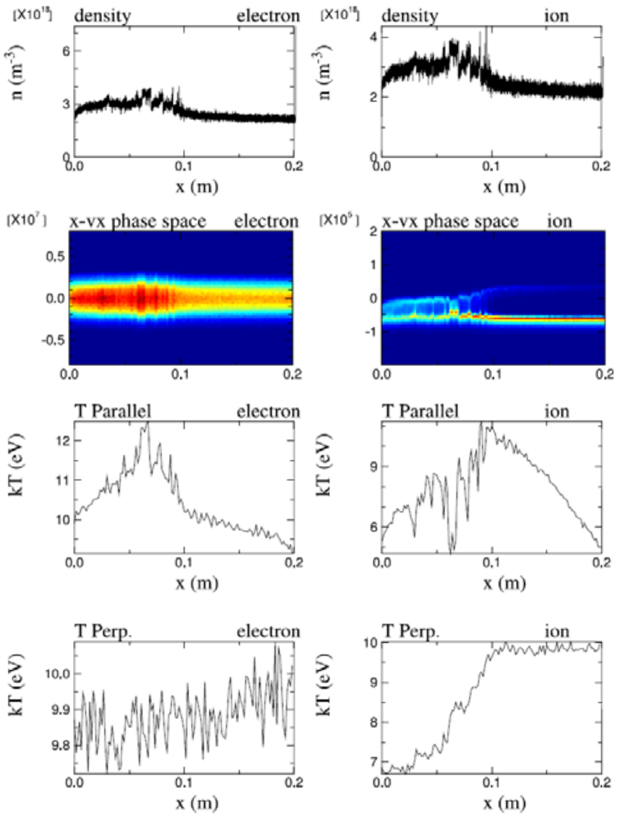

Fig.4. The simulation results of density, phase space, temperature at $t = 8\times10^{-6}$ s

Table I. Simulation parameters

System length	$L = 0.2$ m
Mass ratio	$m_i/m_e = 1836$
Electron source temperature	$kT_e0 = 10$ eV
Ion source temperature	$kT_i0 = 10$ eV
Source particle density	$n_{e0} = n_{i0} = 5.6\times10^{18}$ m^{-3}
Neutral gas temperature	$kT_{n0} = 0.026$ eV
Neutral gas pressure	$p_{n0} = 0.1$ mTorr

4. Discussions

The results show that the neutral gas can affect the plasma and decrease the total heat flux of the plasma. However, in high density plasma, the Coulomb collision can become dominate compare to plasma-neutral collisions because of the high density plasma and long system length. In PIC simulation, Coulomb collision is not treated appropriately due to the size of super-particle.

Rather than Coulomb collision, other atomic processes should be included too. Recombination process is believed to play a crucial role in detached plasma [5]. Thus, our future plan is to include the Coulomb collision by using the Nanbu method [6] and also the recombination process.

Acknowledgments

This work is supported by MEXT scholarships from Japanese government.

References

[1] G.F. Matthews: J. Nucl. Mater. **220-222** (1995) 104-116.

[2] S. Nakazawa, N. Nakajima, M. Okamoto, and N. Ohyabu: Plasma Phys. Control. Fusion **42** (2000) 401-413.

[3] O. V. Batishchev, S. I. Krasheninnikov, P. J. Catto, A. A. Batishcheva, D. J. Sigmar, X. Q. Xu, J. A. Byers, T. D. Rognlien, R. H. Cohen, M. M. Shoucri, and I. P. Shkarofskii: Phys. Plasmas **4** (1997) 1672-1680.

[4] V. Vahedi and M. Surendra: Comput. Phys. Commun. **87** (1995) 179-198.

[5] S. I. Krasheninnikov, A. Y. Pigarov, D. A. Knoll, B. LaBombard, B. Lipschultz, D. J. Sigmar, T. K. Soboleva, J. L. Terry, and F. Wising: Phys. Plasmas **4** (1997) 1638-1646.

[6] K. Nanbu: IEEE Trans. Plasma Sci., **28** (3) (2000) 971–990.