§8. Effect of Radiation Power Loss Due to Ne Impurity Gas Puff for Ergodic Layer

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Reducing high heat load on divertor plates is one of issues to prevent serious damage of divertor plates in future fusion devices such as the ITER, a DEMO and a LHD-type reactor (FFHR)[1]. Gas injection into divertor plasma is one feasible idea to reduce the heat load on divertor plates, since impurity gas causes radiation power loss and decreases electron temperature, which would result in plasma detachment. There are several works considering the effect of gas puff for scrape-off layer and divertor region for ITER[2,3] and JT-60SA[4] by using transport codes. Neon was found to be the optimum candidate to get high effect of impurity radiation loss for the ITER divertor[5].

Ergodic layer surrounding a core plasma has very long field connection lengths from 1 m up to 10^5 m in the LHD. Flux of charged particles onto the divertor plates has strong correlation with field connection lengths in LHD and higher fluxes are measured at places with higher connection lengths. In order to reduce heat load on divertor plates, it would be needed to establish plasma detachment at divertor plasma by reducing electron temperature.

Ne gas puff into the ergodic layer could reduce electron temperature and particle flux. In our previous work we examined the effect of Ne radiation power loss to plasma with one zone model[6]. Ne gas puff can reduce electron temperature down to 1eV within 0.7s and this effect does not depend on initial electron temperature from 10eV to 300eV if gas puff rate is high enough with 1% contamination rate. If the contamination rate is 0.1%, electron temperature reaches 3eV after 1s if initial electron temperature is less than 100eV. If initial electron temperature is 300eV for 0.1% contamination case, electron temperature becomes only 200eV after 1s.

In this work we examine the effect of radiation power loss by puffing impurity Ne gas for ergodic layer by considering one dimensional multi-fluids model. Time evolution of impurity densities and electron temperature caused by radiation power loss is to be examined. Fluid dynamics are solved with particle conservation equations, momentum conservation equations, and energy conservation equations for electron, proton, neutral hydrogen, and neon atom and ions:

$$\frac{\partial n_a}{\partial t} + \frac{\partial}{\partial s}(n_a v_a) = G_a, \qquad (1)$$

$$m_a n_a \frac{\partial v_a}{\partial t} + m_a n_a v_a \frac{\partial v_a}{\partial s} + m_a v_a G_a + \frac{\partial}{\partial s}(n_a k T_a) = R_a, \qquad (2)$$

$$\frac{3}{2} n_a k \frac{\partial T_a}{\partial t} + k T_a n_a \frac{\partial v_a}{\partial s} + \frac{3}{2} n_a v_a \frac{\partial k T_a}{\partial s} + G_a\left(\frac{3}{2} k T_a - \frac{1}{2} m_a v_a^2\right) - v_a R_a + \frac{\partial}{\partial s}\left(\kappa \frac{\partial T_a}{\partial s}\right) = \varepsilon_a. \qquad (3)$$

Source terms in eq. (1) are described as follows:

$$G_p = S_H n_e n_{H0} - \alpha n_e n_p - CX_H n_p n_{Ne0} + \sum_q CX_{Ne}(q) n_{H0} n_{Ne}(q), \qquad (4)$$

$$G_{H0} = -G_p, \qquad (5)$$

$$G_{Ne0} = -S_{Ne0} n_e n_{Ne0} - \alpha_{Ne1} n_e n_{Ne}(1) - CX_H n_p n_{Ne0} + CX_{Ne}(1) n_{H0} n_{Ne}(1), \qquad (6)$$

$$\begin{aligned} G_{Ne}(q) = &-S_{Ne}(q) n_e n_{Ne}(q) - \alpha_{Ne}(q) n_e n_{Ne}(q) \\ &+ S_{Ne}(q-1) n_e n_{Ne}(q-1) + \alpha_{Ne}(q+1) n_e n_{Ne}(q+1) \\ &- CX_{Ne}(q) n_{H0} n_{Ne}(q) + CX_{Ne}(q+1) n_{H0} n_{Ne}(q+1), \end{aligned} \qquad (7)$$

where n_a is number density of species a and $n_{Ne}(q)$ is number density of neon ion in charge state q. Atomic processes, i.e. ionization (S_a), recombination (α_a), and charge exchange (CX_a) processes are considered in above source terms. Charge neutrality, $n_e = n_p + \Sigma_q q n_{Ne}(q)$ is also assumed. Ionization rate coefficients are taken from Voronov[7]. Dielectronic recombination rate coefficients are taken from Mazzotta et al.[8] and radiative recombination rate coefficients are calculated with a Fortran subroutine written by D. Verner[9].

Source terms in eqs. (2) and (3) are similarly described carefully. The radiation power coefficients due to line transitions, radiative recombination, and Bremsstrhalung by Ne and H are taken from ADAS[10]. We ignore the effect of recycling of gas. Free boundary is assumed. Ne gas is injected uniformly with zero velocity. Performing numerical calculations of this multi-fluids model, we will examine the effect of radiation power loss and atomic processes to dynamics of multi-fluids and the relation with field connection lengths to reduce heat flux to divertor plates.

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