21PA-032

Simulation analysis of background plasma in GAMMA 10/PDX by using multi-species fluid code

多流体コードを用いたGAMMA 10/PDX背景プラズマの数値解析

Hisato Takeda[1)], Yousuke Nakashima[1)], Akiyoshi Hatayama[2)], Kazuya Ichimura[1)], Miki Iwamoto[1)], Yasunari Hosoda[1)], Keita Shimizu[1)], Kazuma Fukui[1)], Oki Kensuke[1)], Mizuki Sakamoto[1)], Tuyoshi Imai[1)] and Makoto Ichimura[1)]

武田寿人[1)], 中嶋洋輔[1)], 畑山明聖[2)], 市村和也[1)], 岩元美樹[1)], 細田甚成[1)], 清水啓太[1)], 福井良磨[1)], 大木健輔[1)], 坂本瑞樹[1)], 今井剛[1)], 市村真[1)]

[1)] *Plasma Research Center, University of Tsukuba*
3-1-1, Tennoudai, Tsukuba 305-8577, Japan
プラズマ研究センター 〒305-8577 つくば市天王台1-1-1

[2)] *Graduate school of Science and Technology, Keio University*
3-14-1, Hiyoshi, Minatokitaku, Yokohama 223-8522, Japan
慶応義塾大学大学院理工学研究科 〒223-8577 横浜市港北区日吉3-14-1

In this study, a single fluid code used for analyzing background plasma at end cell in the GAMMA 10/PDX is expanded to multi-fluid code in order to evaluate the impurity ion effects. The distribution of injected impurity and increase electron density for decrease electron temperature is observed from first calculation results. In the paper, we will report detailed simulation results of heat and particle loads on the target plate and impurity ion transport under the condition of impurity gas injection by using Multi-fluid code.

1. Introduction

Divertor plasma physics have been studied by introducing the divertor simulation experimental module in the GAMMA 10/PDX a tandem mirror in the Plasma Research Center at University of Tsukuba [1,2]. In this study, injecting neutral or impurity gases in edge plasma is performed for reduction of heat load and particle flux on the target plate.

The processes of reducing particle and heat fluxes toward the divertor plate include many physical mechanisms. Therefore, numerical simulation is very useful to investigate the effects of the particle and heat reduction and also plasma and impurity ion transport. In previous study, edge plasma in GAMMA 10/PDX is analyzed by using a single fluid code [3]. For further detailed analysis, the single fluid code is to multi-fluid code.

This paper presents the first results of numerical simulation divertor simulation experiments injected neutral or impurity gas into end-loss plasma in GAMMA 10/PDX by using multi-fluid code. The fluid model of the multi-fluid code is based on the same model as B2 without the effects of drift and plasma currents [4].

2. Mesh structure

The area, west plug/barrier and end cells, which is applied this simulation code is shown in Fig. 1. A cylindrical mesh structure is adapted to the configuration of magnetic field from the west plug/barrier cell to end cell. The mesh structure is 0 ~ 0.15 m in the radial (x axis) direction and 0 ~ 3.2 m in the z axial direction.

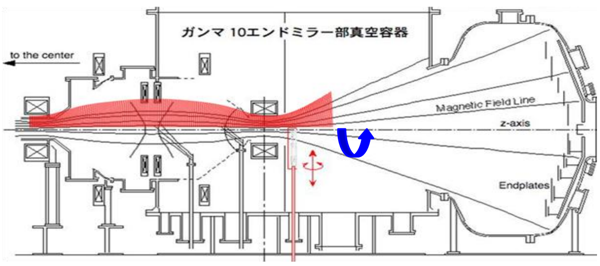

Fig.1 Mesh structure in GAMMA 10 west plug/barrier and end cell.

In GAMMA 10/PDX, hydrogen plasma is generated in the central-cell mainly and flows out through plug/barrier-cell to end-cell. Therefore, plasma parameters at plasma upstream region on the left-side of the Fig. 1 are defined as fixed values. The divertor plate made of tungsten is introduced at the end of mesh. Under the condition of neutral or impurity gas injection experiments, the gases are injected plasma discharge. Therefore, neutral or impurity gases are assumed to be distributed with uniformity in the calculation area among 10.04 ~ 10.70 m and exponential decrease in other region.

3. The multi-fluid equations

The fluid equations solved by multi-fluid code are provided in reference [3]. The temperature of impurity ions is assumed as constant (room temperature). In electron and ion energy balance equation, only the energy relaxation term between electron/ion and impurity ion has been taken into account in this preliminary simulation. In the future, electron energy loss due to impurity radiation will be taken into account. Continuity and momentum balance equations are shown below:

Continuity of species a ($1 \le a \le N$);

$$\frac{\partial n_a}{\partial t}+\frac{\partial}{\partial x}(n_a u_a)+\frac{\partial}{\partial y}(n_a v_a)=S_n^a$$

Momentum balance of species a ($1 \le a \le N$);

$$\frac{\partial}{\partial t}(m_a n_a u_{//a})+\frac{\partial}{\partial x}\left(m_a n_a u_a u_{//a}-\eta_x^a\frac{\partial u_{//a}}{\partial x}\right)$$
$$+\frac{\partial}{\partial y}\left(m_a n_a v_a u_{//a}-\eta_y^a\frac{\partial u_{//a}}{\partial y}\right)$$
$$=\frac{B_\theta}{B}\left[-\frac{\partial p_a}{\partial x}-\frac{Z_a n_a}{n_e}\frac{\partial p_e}{\partial x}+c_e\left(\frac{Z_a}{Z_{eff}}-1\right)Z_a n_a\frac{\partial T_e}{\partial x}\right.$$
$$\left.+c_i\left(\frac{Z_a}{Z_{eff}}-1\right)Z_a n_a\frac{\partial T_i}{\partial x}\right]+\sum_{b=1}^{N}F_{ab}+S_{mu//}^a,$$

where, generation or loss terms, *S*, which exist in the equations are included in atomic molecular processes shown in Table I.

Table I. Atomic-molecular interactions

Ionization	$H_0 + e \rightarrow H^+ + e + e$
	$Ar + e \rightarrow Ar^+ + e + e$
Charge exchange	$H_0 + H^+ \rightarrow H^+ + H_0$
	$H^+ + Ar \rightarrow H_0 + Ar^+$
Recombination	$H^+ + e \rightarrow H_0$
	$Ar^+ + e \rightarrow Ar$

4. Simulation results and discussion

Impurity gas (Ar) is injected into end-loss plasma. Recycling gas from the target plate is considered as only neutral hydrogen atoms. The end-loss plasma flows are assumed to be fixed at the entrance. The plasma are defined as n_i ~10^{19} m^{-3}, T_i ~100 eV and T_e ~30 eV.

Fig. 2 shows the simulation results of heat flux and hydrogen ion particle flux on the target plate under the condition of argon gas injection. The amount of argon gas is given for 1.0 to 10.0 × 10^{17} m^{-3}. Hydrogen particle flux on the target plate has peak at the injected Ar density of 5.0 × 10^{17} m^{-3} and tends to decrease with increasing Ar density from 5.0 × 10^{17} m^{-3} to 1.0 × 10^{18} m^{-3}. On the other hand, heat flux increases with increasing amount of injected neutral Ar density. However, increase heat flux is saturated in the injected neutral Ar density of beyond 7 × 10^{17} m^{-3}. Decrease both heat and particle fluxes are not observed obviously at the present density range.

In GAMMA 10/PDX, the ion temperature is about 3 times larger than the electron temperature. It is difficult to decrease electron energy due to energy transport from ion to electron. From above reason, for decrease heat load and particle flux on the target plate, the ion energy needs to decrease sufficiently.

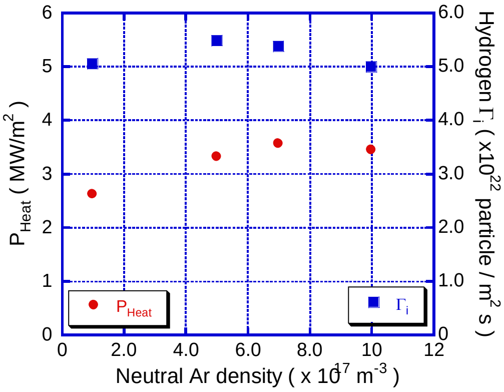

Fig. 2 Simulation result of heat and particle fluxes on the target plate.

5. Summary

Behavior of background plasma and impurity ion such as argon in the GAMMA 10 west plug/barrier cell and end cell are calculated successfully by using multi-fluid code under the condition of impurity injection. The reduction heat load and particle flux on the target plate is not observed obviously. Therefore, introducing not only the relaxation term but also electron energy loss due to impurity radiation is needed in the fluid code.

6. Acknowledgments

The study has been supported by the bidirectional collaboration research program in the University of Tsukuba (NIFS14KUGM086). The authors would like to thank the member of the GAMMA 10.

References

[1] Y. Nakashima, et al. Fusion Sci. Technol. **59** No. 1T 61 (2011).

[2] Y. Nakashima, et al. J. Nucl. Mater. **438** S738 (2013).

[3] H. Takeda, et al. Contrib. Plasma Phys. **54**, 605 (2014).

[4] B.J. Braams, NET Rep. **68** EURFU/X-80/87/68, CEC, Brussels (1987).