Simulations of ITER plasma during pellet injection

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Introduction

Pellet injection has become a leading technique not only for fuelling purposes, but also for controlling tokamak plasmas in both core and edge regions, such as ELMs [1]. In this work, two NGS scaling laws for pellet ablation rate have been investigated with BALDUR code [2]. The first pellet ablation model was developed by P.B. Parks and R. J. Turnbull [3] in 1970s; it was a one-dimensional approach for a monoenergetic electron heat flux model based on the steady state approximations and on the assumption of spherically symmetric hydrodynamic expansion, which results in the following formula:

$$\frac{dN}{dt} = 1.12 \times 10^{16} n_e^{0.333} T_e^{1.64} r_p^{1.333} M_i^{-0.333} \quad . \qquad (1)$$

The other model was developed by B.V. Kuteev [4] as a two-dimensional approach with electron and ion ablation, which took into account a Maxwellian energy distribution of the background plasma and the pellet shape modification during ablation. The scaling law from Kuteev model is given by

$$\frac{dN}{dt} = 3.465 \times 10^{14} n_e^{0.453} T_e^{1.72} r_p^{1.443} M_i^{-0.283} \quad . \qquad (2)$$

In Eqns. (1) and (2), *dN/dt* is the ablation rate in atoms/s. n_e and T_e are the electron density in cm^{-3} and temperature in eV, respectively. r_p is the pellet radius in cm and M_i is the mass of the pellet material in atomic units.

Simulation Results

The ablation rates of two pellet models were utilized together with other modules in 1.5D BALDUR code. It shows in Figure 1 that the pellet ablation rate peak taken from the BALDUR simulation using Kuteev model (Eq.[2]) yields higher values than that using Parks and Turnbull model (Eq.[1]). In addition, it can be seen that the location of the peak from the simulation using Parks model is deeper than that using Kuteev model, in which the peak locations are separated by a distance of approximately 18 cm.

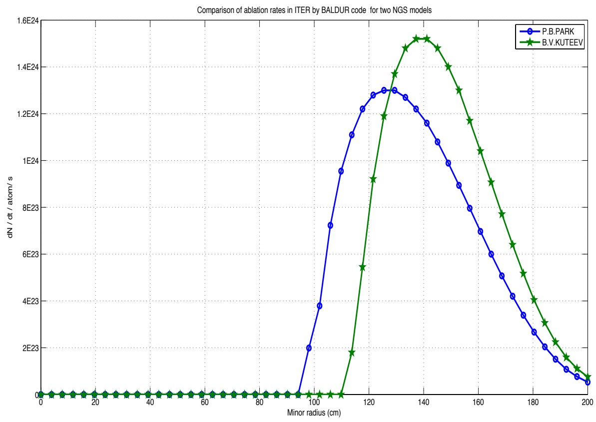

Figure 1: Comparison of the NGS ablation rate profiles obtained from Kuteev model (green) and Parks and Turnbull model (blue). The vertical axis is dN/dt (atoms/s) and the horizontal axis is the minor radius.

In Figure 2, the results from electron density and the plasma temperature investigation are displayed when the pellet size varies. The deuterium pellet velocity of 300 m/s is applied with different pellet radii: 2, 3, 4 mm. It can be seen that when the pellet radius increases, the peak value for electron density increases significantly due to more electron converted from pellet. The electron temperature of the plasma noticeably decreases due to the plasma energy distributed to pellet. It can also be seen that the ablation peak is deeper as the pellet radius increases.

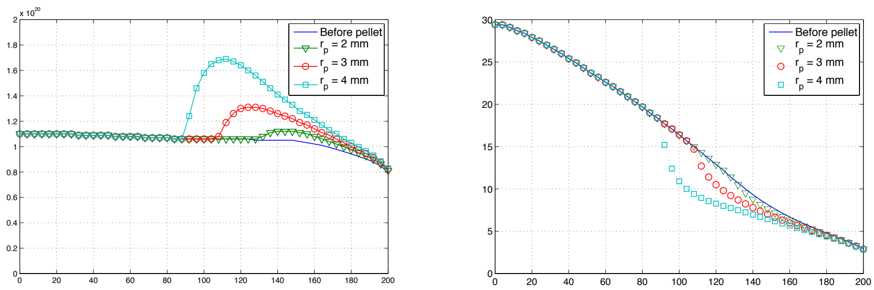

Figure 2: Effect of pellet radius on plasma electron density and temperature from simulation using Parks and Turnbull NGS model. On the left, the vertical axis is the electron density (particles per m^3); while on the right, the vertical axis is the electron temperature (keV). The horizontal axis is a minor radius.

Figure 3 shows the impact of pellet velocity on the electron density and temperature profiles. Note that the pellet velocity is varied as 300, 350, 400 m/s with the pellet radius of 3mm. It can be seen that when the velocity increases, the electron density of plasma remains constant, but the pellet penetrates more deeply into the plasma core due to its increased kinetic energy.

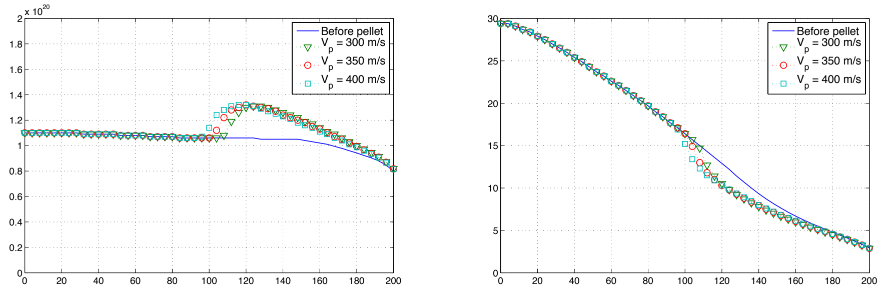

Figure 3: Effect of pellet velocity on plasma electron density and temperature of plasma from simulation using Parks and Turnbull NGS model. On the left, the vertical axis is the electron temperature (keV); while on the right, the vertical axis is the electron density (particles per m^3). The horizontal axis is a minor radius (m).

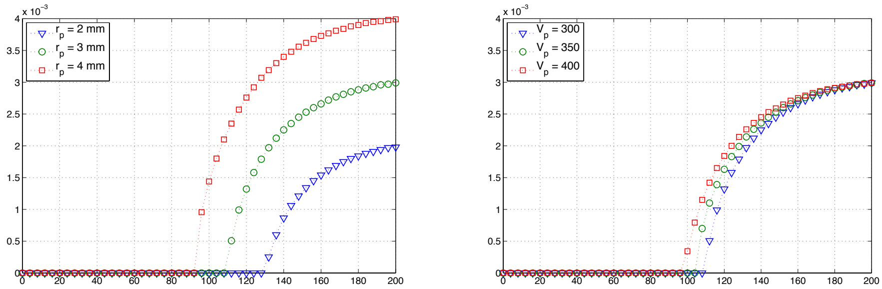

Figure 4: Plots of the pellet radius and the plasma minor radius computed by Parks and Turnbull model, at different pellet initial radii and velocities. The vertical axis is the pellet radius (m). The horizontal axis is the minor radius (m).

Table 4.1: Summary of pellet radius and maximum electron density with constant velocity.

Initial velocity (m/s)	Initial pellet radius (mm)	pellet radius at maximum ablation rate (mm)	$r_{initial} / r_{peak}$	Maximum electron density (m^{-3})	Pellet location at maximum ablation rate (minor radius cm)
300	2.0	1.25	0.625	1.17×10^{20}	115
300	3.0	1.85	0.612	1.34×10^{20}	125
300	4.0	2.58	0.645	1.70×10^{20}	148

Now we investigate the effects of the pellet radius by means of varying the initial size and velocity of the deuterium pellet. Figure 4 (left) shows the results of simulation by varying the initial pellet size with the: initial radii of 2, 3, 4 mm with a constant velocity (300 m/s) , while Figure 4 (right) shows the results of simulation by varying the initial velocity of pellet with the initial velocities of 300, 350, 400 m/s at a constant radius (3 mm). From the results show in Table 1 and 2, it can be seen that the maximum of ablation rate occurs when the pellet radius is decrease to 63.2 % of its initial radius and is independent of either velocity or size of the pellet. The locations of electron density peaks are shown in Figure 2 (left) and Figure 3 (left), where a local maximum of ablation rate occurs.

Table 4.2: Summary of pellet radius and maximum electron density with constant radius.

Initial velocity (m/s)	Initial pellet radius (mm)	pellet radius at maximum ablation rate (mm)	$r_{initial} / r_{peak}$	Maximum electron density (m^{-3})	Pellet location at maximum ablation rate (minor radius cm)
300	3.0	1.75	0.583	1.35×10^{20}	125
350	3.0	1.90	0.633	1.35×10^{20}	125
400	3.0	1.96	0.650	1.35×10^{20}	125

Conclusions

It is found that the peak of pellet ablation rate given by Kuteev model is higher than that given by Parks model. The simulation results show that an injection of deuterium pellets can increase plasma density which serves as an effective means to replenish plasma. It is also observed that the maximum pellet ablation rate occurs when the radius of pellet is reduced to about 63.2% of the original radius, independent of initial radius and velocity.

Acknowledgements

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