The properties of supersonic molecular beam injection in L-mode, H-mode and I-mode plasmas

J. Chen[1], J. Huang[1], Y. Xu[1], J. Cheng[1], X. Q. Wang[1], H. F. Liu[1], X. Zhang[1], H. Liu[1], J. F. Shen[1], C. J. Tang[2]

[1] *Institute of Fusion Science, School of Physical Science and Technology, Southwest Jiaotong University, Chengdu 610031, China*

[2] *College of Physics, Sichuan University, Chengdu 610064, China*

The plasma fueling is very important for fusion plasma to control the density. Several methods have been developed for plasma fueling, such as supersonic molecular beam injection (SMBI) [1], pellet injection (PI) [2] and gas puffing (GP) [3]. For SMBI, its injection depth is deeper than GP, furthermore its cost is much lower than PI. Therefore, SMBI is a good plasma fueling method. In addition to plasma fueling, SMBI is also conducive to mitigate the edge localized mode (ELM) [4-5]. It is important to understand the injection properties of SMBI in different confinement plasma.

The process of SMBI injection into plasma is mainly depended on the four collision reactions. Based on these four reactions and Braginskii equations, a seven-field two-fluid model of SMBI is derived. In this model, the transport mainly includes the following three process: molecule transport, atom transport and plasma transport. The model includes the plasma density, heat and momentum transport equations for plasma, and the density and momentum transport equations for neutral particles [6].

In these seven-field two-fluid model, a set of evolution equations for plasma density N_i, ion temperature T_i, electron temperature T_e, parallel ion velocity $V_{\|}$, atom density N_a, molecule density N_m and radial molecule velocity V_m are developed to simulate the process of SMBI.

The initial density and temperature profiles are shown in Fig. 1. The simulation region in radial is $0.4 \leq \psi \leq 1.1$, where ψ is the normalized poloidal flux. The density N_i is normalized to $N_0 = 1 \times 10^{19} m^{-3}$ and the temperature is normalized to 10ev. In the next, the injection of SMBI with different density and velocity into the L-mode and H-mode plasmas has been simulated.

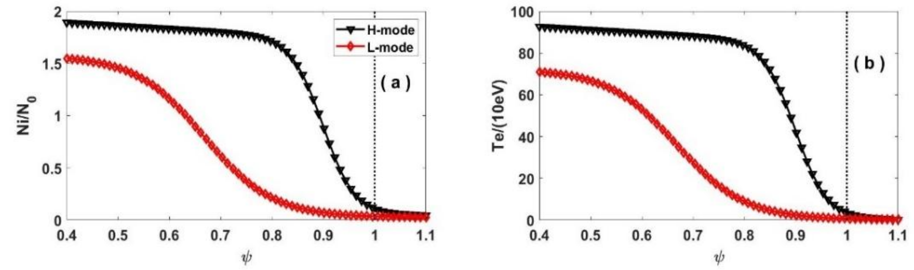

Figure 1. *The initial profiles: (a) density N_i for L-mode and H-mode, (b) electron temperature T_e for L-mode and H-mode. The vertical dotted line represents the position of the separatrix.*

The variations of plasma parameters when SMBI with different V_m and same N_m inject into L-mode and H-mode plasmas are shown in Fig. 2. The density of SMBI is $N_m = 0.5N_0$. It is obvious that the deposition position of molecular moves inward with the increase of molecular velocity, and the peak positions of plasma density and molecular dissociation rate also move inward for both H-mode or L-mode plasmas. We can use peak position of S_{diss} or N_i to define the injection depth of SMBI. To compare the injection properties of SMBI in L-mode and H-mode plasmas, the tendencies of variation of parameter profiles are similar but the differences between them are also obvious. For H-mode, there is a pedestal for both density and temperature in the edge of H-mode plasma, which prevents the SMB injection and results in a narrower deposition profile of N_m.

The variations of N_m, N_i and S_{diss} when SMBI with different densities and same velocity inject into L-mode and H-mode plasmas are shown in Fig. 3. The velocity of SMBI is $V_m = 1000m/s$. From the figure, as N_m increases, the injection depth and peak value of N_i also increase, whatever SMBI injects into H-mode or L-mode plasma. In H-mode plasma, the variation of injection depth is smaller than that in L-mode plasma. Because S_{diss} is very large in the pedestal top, the main deposition position of SMBI is around the pedestal. To compare with the results in Figs. 2(b) and (e), the injection depth and the peak value of N_i for SMBI with $N_m = N_0$ and $V_m = 1000m/s$ injection is nearly the same with that for SMBI with $N_m = 0.5N_0$ and $V_m = 2000m/s$ injection. It means SMBI with the same molecular injection flux, i.e., $\Gamma = V_m \times N_m$, may have the similar injection property.

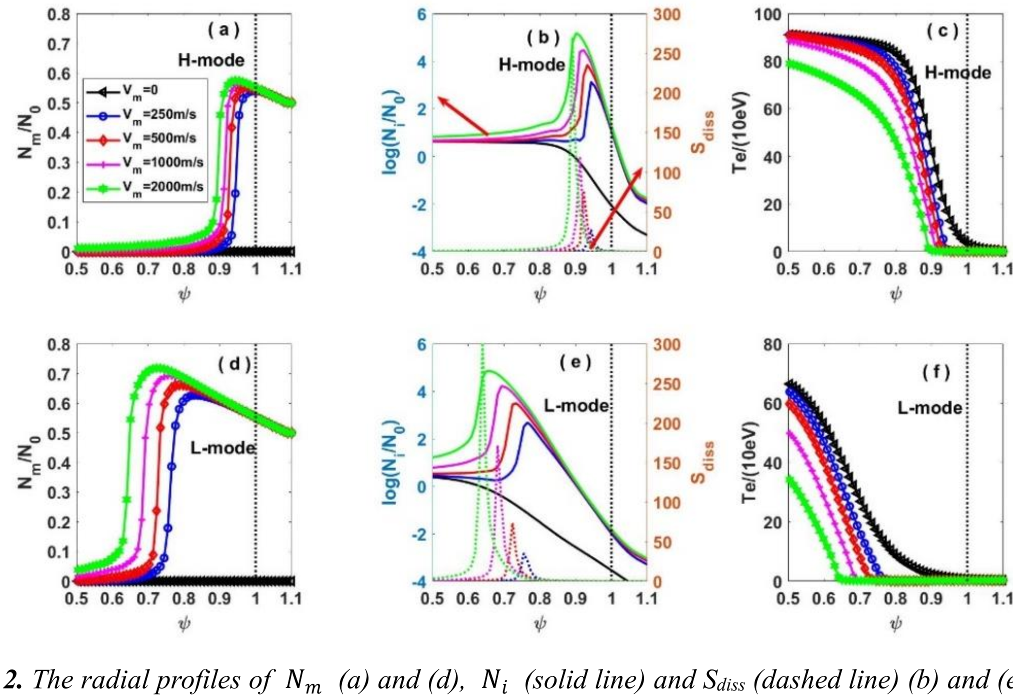

Figure 2. *The radial profiles of* N_m *(a) and (d),* N_i *(solid line) and* S_{diss} *(dashed line) (b) and (e), and* T_e *(c) and (f) for SMBI. (a), (b), (c) for H-mode and (d), (e), (f) for L-mode.*

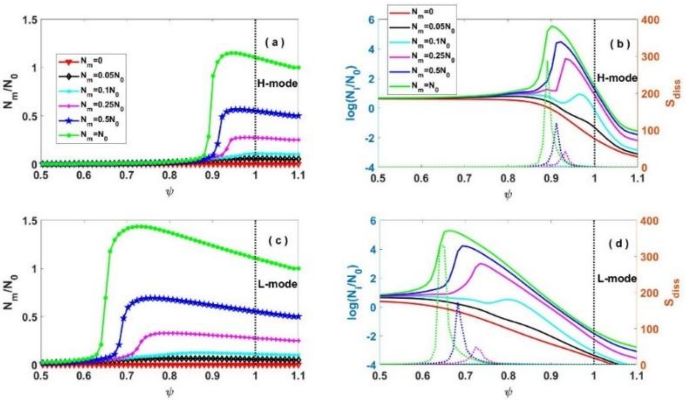

Figure 3. *The radial profiles of* N_m *(a) and (c), and* N_i *(solid line) and* S_{diss} *(dotted line) (b) and (d) for SMBI with* $V_m = 1000m/s$.

In previous, the variations of plasma parameters after SMBI injection and the injection depth for various injection parameters have been studied. But both the variations of parameters and the injection depth cannot represent the injection effect very well. Therefore, we define the relative injection efficiency of SMBI as $\delta N_{i,all}/N_m V_m$. Here, $\delta N_{i,all}$ is the total increment of N_i caused by SMBI. The injection depths and $\delta N_{i,all}$ and the relative injection efficiency for different V_m and different N_m are shown in Fig. 4 and Fig.5, respectively. From Figs. 4 and 5, both the injection depth and $\delta N_{i,all}$ is approximately linear increase with V_m or N_m. It is obviously that the relative efficiency of L-mode is always higher than that of H-mode

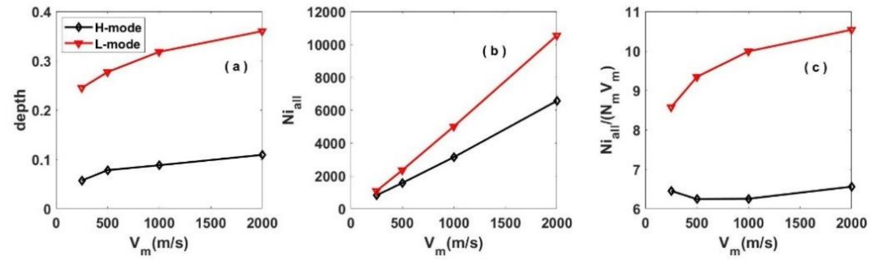

Figure 4. *(a) Molecular injection depth, (b)the total increment of* N_i *, and (c) the relative efficiency of molecules vs.* V_m.

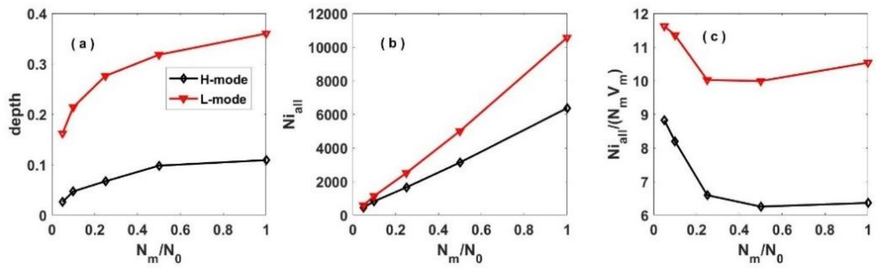

Figure 5. *(a) Molecular injection depth, (b)the total increment of* N_i *and (c) the relative efficiency of molecules vs.* N_m.

SMBI in H-mode plasma has lower relative injection efficiently because of the pedestal. In the next, we studied whether density pedestal or temperature pedestal had a greater effect to suppress the SMBI injection in H-mode. Figure 6 shows the variations of N_m, N_i and S_{diss}

when SMBI injects in only temperature pedestal, i.e., I-mode, and only density pedestal. Although the injection depth of SMBI in only density pedestal plasma is slightly deeper than that in I-mode plasma, the injection properties of SMBI in I-mode plasma and only density pedestal plasma are similar. The results show both the temperature pedestal and density pedestal are the important factors to suppress SMBI injection in H-mode plasma.

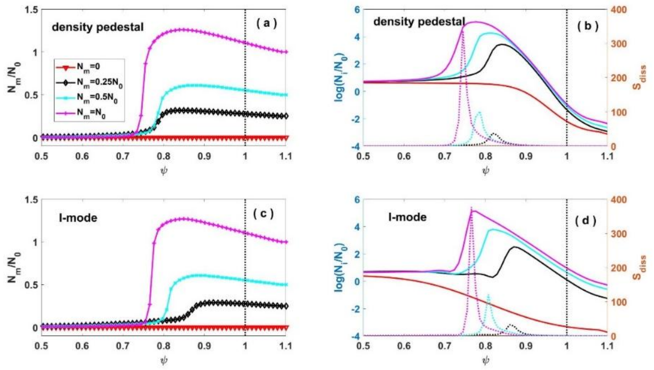

Figure 6. *The radial profile of* N_m *(a) and (c),* N_i *(solid line) and* S_{diss} *(dashed line) (b) and (d).*

Figure 7 shows the comparison of the results of SMBI in H-mode, L-mode, I-mode and only density pedestal plasmas. From figure 7, it is found that in L-mode plasma SMBI has the best injection effect, i.e., injection depth and relative efficiency, the second is SMBI in only density pedestal plasma, the worst is SMBI in H-mode plasma.

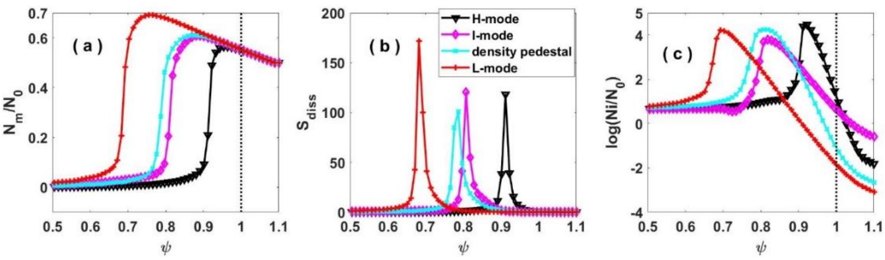

Figure 7. *The comparison the radial profile of (a)*N_m*, (b)* S_{diss}*, and (c)* N_i*.*

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Reference

[1] Yu, D. L., et al. Nuclear fusion 50.3 (2010): 035009.

[2] Baylor, L. R., et al. Physics of Plasmas 7.5 (2000): 1878-1885.

[3] Sajjad, S., et al. Physics Letters A 373.12-13 (2009): 1133-1139.

[4] Yu, D. L., et al. Nuclear Fusion 52.8 (2012): 082001.

[5] Xiao, W. W., et al. Nuclear Fusion 52.11 (2012): 114027.

[6] Wang, Z. H., et al. Nuclear Fusion 54.4 (2014): 043019.