

Influence of Gas Puffing on Edge Plasma Characteristics in HT-7 Tokamak

B J Ding, J F Shan, F K Liu, M Wang, Y L Qin, M H Li, W K Li, D X Wang, J Q Feng, Y X

Jie, Y W Sun, B Shen, X M Wang, J H Wu, J Wang, X Gao, Y P Zhao, and HT-7 Group

Institute of Plasma Physics, Chinese Academy of Sciences, P R China, Hefei, 230031

Abstract Similar to CD₄ puffing, experiments with D₂ puffing demonstrate again that the wave-plasma coupling is improved by the gas injection around the lower hybrid wave (LHW) antenna in HT-7. Langmuir measurements indicate that the gas puffing effectively increases the density and decreases the temperature in SOL. Studies show that the puffed D₂ is ionized by both LHW electric field and plasma temperature. The coupling improvement by the gas puffing is ascribed to the increase of central line averaged density and the local increase of density at the grill mouth due to the magnetic connection. Comparison of D₂ and CD₄ puffing shows that D₂ improves coupling better with less effect on core density.

1. Introduction Theory studies [1,2] indicate that the plasma density at the grill mouth ($n_{e,grill}$) and its gradient are two key factors determining LHW-plasma coupling. In order to avoid heavy heat load and to satisfy different plasma configurations, it is necessary to increase the distance between antenna and plasma. As a result, the coupling of LHW and plasma will be deteriorated due to the decrease of $n_{e,grill}$. To solve the long distance coupling between LHW and plasma, a kind of gas (e.g., CD₄, D₂) is utilized to increase $n_{e,grill}$. Such long distance coupling experiments have been done and analyzed in JT-60U, Tore-supra, and JET, on all of which the gas is injected from one side of the LHW antenna [3-6]. In HT-7, LHW-plasma coupling was improved by CD₄ puffed around the LHW antenna [7]. Here, the mechanism of gas ionization will be analyzed and the edge plasma characteristics in the case of gas puffing will be investigated. Also, the influence of D₂ and CD₄ on plasma will be compared.

2. Experiments description The experiments were performed with the same gas injection structure around the LHW grill as CD₄ in 2007 campaign [7], with plasma current $I_p=100\text{kA}$, magnetic field on the magnetic axis $B_t=1.8\text{T}$, central line averaged density $n_e=0.5\times 10^{19}\text{m}^{-3}$. D₂ was chosen as the puffing gas. Also, a reciprocating Langmuir probe is taken to measure the profiles of density and temperature in the edge region. The distance (d) between LHW antenna and plasma was modified by moving the plasma centre in the horizontal direction.

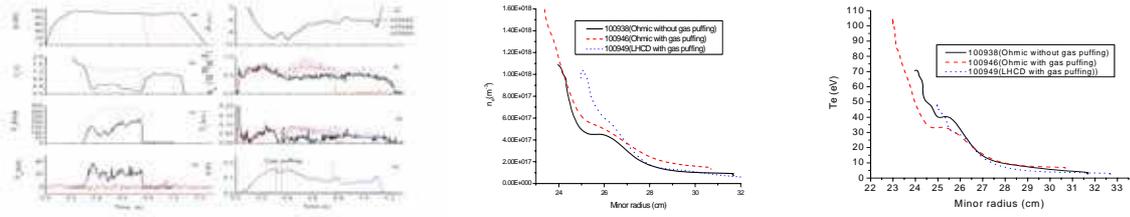


Fig. 1 Typical waveforms for D₂ puffing Fig. 2 Edge density profile Fig. 3 Edge temperature profile

3. Experimental results and analysis The typical waveforms are shown in Fig. 1, in which I_p , loop voltage (V_p), input power of LHW (P_{in}), reflected power of LHW (P_{re}), movement of the plasma centre in the horizontal direction (ΔR), n_e , neutral deuterium radiation (D_α), and the distance (d) are plotted from (a) to (h). Also, the gas puffing signals are also plotted in (h). Seen from 100942 without gas puffing, the LHW-plasma coupling is not good when d is large, indicating $n_{e,grill}$ is not enough to satisfy LHW-plasma coupling condition. P_{in} increases and P_{re} almost keeps constant with the decrease of d , implying $n_{e,grill}$ is increased with the decreasing d . As a result, the loop voltage decreases drastically after 0.6s. With a same distance as 100942, D₂ is puffed at 0.35s in 100950. It is seen that P_{in} increases quickly and more LHW power is injected into plasma. This is mainly due to the fact the puffed D₂ increases the plasma density, which can be seen from frame (f). Another discharge 100946 (with D₂ and w/o LHW) is performed to investigate the mechanism of neutral gas ionization (Fig.1). It is seen that in 100942 (only LHW), n_e is the lowest, followed by 100946, and the last one is 100950 (LHW + D₂), meaning that the puffed D₂ is ionized by both LHW and plasma temperature in 100950. Simple estimation indicates that at least half of the contribution of density comes from plasma temperature in the present parameters. Generally, the ionization is much dependant of the averaged ionization rate $\langle\sigma v\rangle$, which is much affected by electron energy (indicated by electron temperature T_e). After the LHW is applied, electron gains additional energy due to the LHW electric field. For $T_e = 10\text{eV}$, estimated from $\Delta W[eV] = \Delta W_{th} + 2W_{sl} = 5.09\sqrt{P_{LH}[MW]} + 0.68P_{LH}$ [6], the total energy gain resulting from LHW is about 3.0eV with the present LHW power P_{LH} . As a result, more neutral gases are ionized in the LHCD case, hence increasing the density.

In order to see the effect of gas puffing on density and temperature in the edge region, 3 cases

are selected: Ohmic plasma without gas puffing (100938), Ohmic plasma with gas puffing (100946), and LHCD plasma with gas puffing (100949). The measured density and temperature profiles in the scrape of layer (SOL) are shown in Fig.2 and Fig. 3. It is seen from Fig. 2 that compared to 100938, density increases after gas puffing (100946), indicating neutral gas is ionized by the temperature and the density in the SOL is increased due to the gas injection. In 100949, the plasma density in the SOL increases, suggesting that the density is modified by LHW and gas injection. The density at the antenna mouth ($\sim 27\text{cm}$) increases from $\sim 3.0 \times 10^{17} \text{m}^{-3}$ to $\sim 3.6 \times 10^{17} \text{m}^{-3}$, making the density satisfy the wave-plasma coupling condition. Furthermore, the density in the SOL in 100949 is much larger than that in 100946, indicating again that apart from the temperature contribution, LHW electric field also contributes to the neutral gas ionization. It is seen that in the SOL the temperature in 100938 is the highest. When the gas (100946, 100949) is puffed, the temperature in front of LHW antenna decreases due to the increased neutral gas. Compared to 100949, the temperature inside further in 100946 is much lower, this is possibly because much energy is used to ionize neutral gas whereas in 100949 both plasma temperature and LHW electric field plays role in ionizing neutral gas, as a result less temperature are cost.

Now we would like to discuss the effect of increased n_e on LHW-plasma coupling by performing a discharge (100364), in which the distance and the density mimic those in 100950 and the density is fed back by the main gas injection which is not magnetically connected to the LHW grill. As shown in Fig. 4, I_p , n_e , P_{in} , P_{re} , reflection coefficient (RC) and horizontal displacement ($\Delta_{//}$) are displayed from top to bottom. Note that only the data in the rectangle region are valid for comparison considering density and distance. In 100942, RC is about 21%. In the gas puffing discharge (100950) near the grill, RC drops to about 5%. In 103464, RC is about 10%. Results suggest that only the increase of n_e with the gas injection not magnetically connected to grill cannot account for the RC decrease when gas puffing near the antenna, implying that the coupling improvement by the gas puffing around the LHW grill is ascribed to the increased n_e and the increased $n_{e,grill}$ due to the magnetic connection.

Two discharges of 93770 (CD_4) and 100950 (D_2) are compared to investigate the influence of D_2 and CD_4 on plasma and coupling (Fig. 5, where I_p , n_e , LHW power (P_{in} , P_{re}), RC, distance (d), gas puffing signal are plotted from (a) to (f)). The gas rate of CD_4 and D_2 are

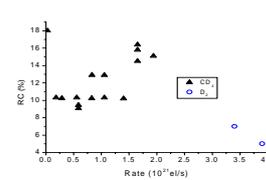
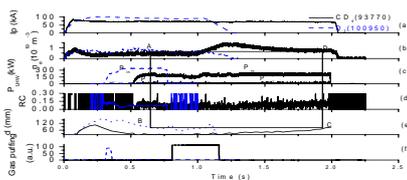
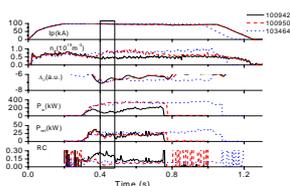


Fig. 4 n_e effect on coupling Fig. 5 Coupling comparison of D_2 and CD_4 Fig. 6 RC reverse gas rate

1.8×10^{21} el/s and 3.4×10^{21} el/s, respectively. For the same distance and density (indicated by ABCD), RC in 100950 is a little smaller than that in 33970. Seen from (b), n_e is much more affected by CD_4 , though the gas rate is Φ_{CD_4} only half of Φ_{D_2} . The dependences of RC on gas rate are shown in Fig. 6. These results suggest that D_2 improves coupling better with less effect on core plasma, in agreement with the obtained results in JET [5]. The different n_e sensitivity on Φ_{CD_4} and Φ_{D_2} is possibly due to different ionization energy for the two gases.

4. Conclusion Similar to CD_4 puffing, experiments with D_2 puffing demonstrate again that the wave-plasma coupling is improved by the gas injection around the LHW antenna in HT-7. Edge density and temperature profiles deduced from Langmuir measurements indicate that gas puffing near the antenna effectively increases the density and decreases the temperature in SOL. Investigation shows that the puffed D_2 is ionized by both LHW electric field and plasma temperature. The coupling improvement by the gas puffing around the LHW grill is ascribed to the increase of n_e and the local increase of $n_{e,grill}$ due to the magnetic connection. Comparison of D_2 and CD_4 puffing shows that D_2 improves coupling better with less effect on the core density, in agreement with the obtained results in JET.

Acknowledgements: This work is supported by the National Natural Science Foundation of China under Grant No. 10575104 and 10875149.

References: [1] Brambilla M, 1976 Nucl. Fusion **16** 47.

[2] Petržilka V A et al., 1991 Nucl. Fusion **31** 1758.

[3] Peysson Y et al, in Fusion Energy 1996 (Proc. 16th Int. Conf. Montreal, 1996), Vol.,3, IAEA, Vienna (1997) 265.

[4] Ide S et al., 1996 Plasma Phys. Contr. Fusion **38** 1645.

[5] Ekedahl A, Granucci G, Mailloux J et al., 2005 Nucl Fusion **45** 351.

[6] Pericoli Ridolfini V, et al., 2004 Plasma Phys. Contr. Fusion **46** 349.

[7] Ding B J et al., 2008 35th EPS Conference Hersonissos, Crete, Greece.