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Hydrogen removal via ICRF technique on HT-7 – experiment and modeling on neutral energies

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Abstract

Hydrogen removal experiment in HT-7 is briefly reported. The modeling effort by a Monte-Carlo transport code, DEGAS 2, was made to elucidate the energies of hydrogen neutrals in the HT-7 RF plasmas. Concentration was paid on the Balmer line emission. The modeling results reveal that the neutral hydrogen atoms in the range of 10–20 eV occupy a high fraction and they could be easily removed. This could be one of the reasons for the easy hydrogen removal via RF technique in HT-7 cleaning. The scheme with RF power at about 10 kW and the deuterium working gas at a pressure about 0.01 Pa, could be an optimized scheme for hydrogen removal.

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Keywords: Hydrogen removal; Neutral energy; DEGAS 2 code

1. Introduction

In the past HT-7 experiments [1], the technique via ion cyclotron resonance frequency (ICRF) was proven to be an effective way to remove hydrogen as well as impurity particles and also for wall conditioning and coating. In these experiments, the hydrogen removal rate is quite higher compared with that by glow-discharge technique. The rate generally increases with ICRF input power and reaches saturation at some point. This suggests a relationship between the removal rate and plasma parameters. Generally, larger heating power would increase ion and electron temperatures and therefore lower charge exchange rate, higher dissociation rates of the desorbed molecules and ionization rates of neutral particles. Moreover, the neutrals which collide walls would have different energies and thus the recycling of neutrals would be influenced. The balance of these processes determines the pumping or removing rates of hydrogen and other impurities.

In 2001 winter campaign, we performed systematically the parametric study on hydrogen removal. The typical plasma parameters are $T_e = 2$–5 eV and $T_i = 0.3$–0.5 keV. This paper briefly report the experimental results related to the hydrogen removal especially the Balmer-α line emission and their profile during the phase of hydrogen removal. The experiment is modeled with DEGAS 2 code [2] and the modeling results are compared with those from experiment. In the modeling, special attention is paid on the Balmer line emission to elucidate the energy of neutral atoms in the RF plasmas. Finally we give discussions and summary.

2. Experiment

HT-7 is a medium sized superconducting tokamak with major radius of 1.22 m and minor radius of 0.32 m. Fig. 1 shows the outline of experimental setup during the phase of wall conditioning. The line emission observation point is just near the poloidal ring limiter head. For

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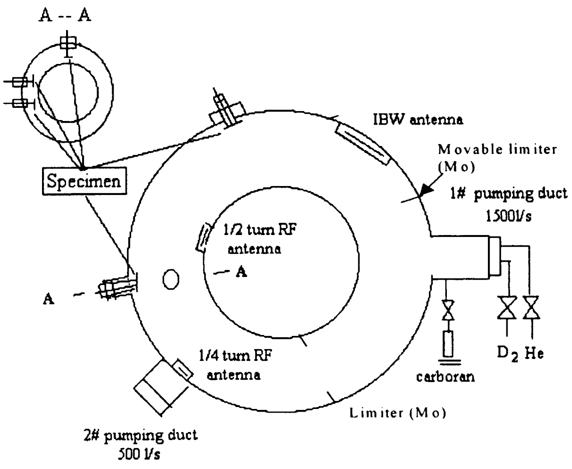

Fig. 1. Experiment setup.

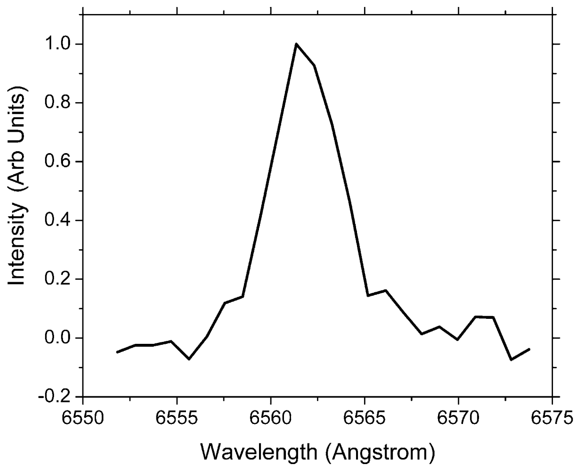

Fig. 2. Balmer-α emission in front of limiter.

hydrogen removal, the working gas can be helium and deuterium. Reported in this paper is the case with deuterium as the working gas.

Several RF input powers, typically 5, 10, 20 and 30 kW were used for hydrogen removal experiment. The filling pressure is 0.01 Pa. The experimental results are quite similar to the results reported before [1]. The rate of hydrogen removal generally increases with RF heating power and reaches saturation at about 10 kW. At the beginning of the pumping, the quadrupole mass spectroscopy data shows the pumping partial pressures of deuterium and hydrogen are 2×10^{-5} and 0.25×10^{-5} Pa, respectively. The ion temperatures is about 0.3–0.5 keV. Electron temperature is about 3–4 eV and the density about $0.5\text{–}3 \times 10^{17}$ m^{-3}. Table 1 gives a summary of the experimental conditions and results.

Fig. 2 reports the Balmer-α line profile in front of the ring limiter when the RF power is 10 kW. Because of the wavelength resolution and line broadening, Dα and Hα cannot be well resolved. To get a better understanding of hydrogen removal via RF in HT-7 experiment, we performed the neutral transport modeling. Special attention is paid on the Hα profile in front of limiters.

3. Modeling

The simulation was performed by DEGAS 2 code [2].

3.1. Geometry and background

For the simplicity, the real geometry was ‘straighten’ out as a ‘box’-like geometry which is illustrated in Fig. 3. The limiter surface is made from graphite and the first wall is stainless steel.

During the period of ICRF conditioning process, the partial pressure of hydrogen neutrals is high and the neutrals would be ionized. So although the working gas is deuterium or helium, there exists high percentage of hydrogen ions. Because the measured ion parameters are for the D ions, we must firstly estimate the energy and density of hydrogen ions with some method in order to put forward the modeling. For the simplification, we adopt here a zero dimensional approximation.

Hydrogen atoms exchange their charges with background deuterium ions, $H + D^+ \rightarrow H^+ + D$ or collide with electrons to become ions. For the estimation, the density of hydrogen ions can be governed by the balance of ionization rates and the loss rates which are domi-

Table 1
The typical plasma parameters and results for hydrogen removal via RF heating working gas: D_2

	Input power/pulse duration		
	10 kW/0.35 s	20 kW/0.35 s	30 kW/0.35 s
T_e (eV)	3	4	5
n_e (10^{17} m^{-3})	0.5	1	3
T_i (keV)	0.3	0.4	0.5
Initial H pumping partial pressure	2×10^{-5}		
Initial D pumping partial pressure	0.25×10^{-5}		

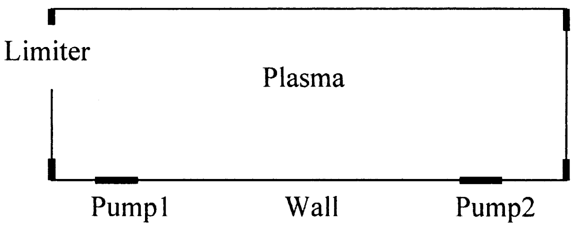

Fig. 3. 'The straighten-out' model of HT-7 geometry.

nated by the charge exchange with neutral hydrogen and deuterium.

$$n_{\mathrm{H}}(n_{\mathrm{e}}R_{\mathrm{i}} + n_{\mathrm{D}^+}R_{\mathrm{chx}}) = n_{\mathrm{H}^+}(n_{\mathrm{D}}R_{\mathrm{chx}}^{\mathrm{DH}} + n_{\mathrm{other}}R_{\mathrm{chx}}^{\mathrm{H\,other}}), \qquad (1)$$

where the second term at right hand which is referred to the charge exchange of the ions with other species, is usually small and can be neglected. These ions make Coloumb collisions with background D^+ ions, which are heated up by the RF heating, to gain the energy. The Coloumb collision time is given by:

$$\tau_{\mathrm{i}} = 6.60 \times 10^{17}\left(\frac{m_{\mathrm{i}}}{m_{\mathrm{p}}}\right)^{1/2}\frac{T_{\mathrm{i}}^{3/2}}{n\ln\Lambda_{\mathrm{i}}}, \qquad (2)$$

where T_i is the ion temperature in keV. In the case of RF heating power of 10 kW, τ_i is about 0.15 s. After a collision, the energy transfer is given by:

$$\frac{\Delta E}{E_{\mathrm{i}}} = \frac{2m_{\mathrm{i}}m_{\mathrm{p}}}{(m_{\mathrm{i}} + m_{\mathrm{p}})^2}. \qquad (3)$$

Then energy gain can be expressed by:

$$\frac{\mathrm{d}E_{\mathrm{p}}}{\mathrm{d}t} = \frac{E_{\mathrm{i}} - E_{\mathrm{p}}}{\tau_{\mathrm{i}}} \times \frac{2m_{\mathrm{i}}m_{\mathrm{p}}}{(m_{\mathrm{i}} + m_{\mathrm{p}})^2}. \qquad (4)$$

During the dwelling time t in the plasmas, hydrogen ions would be energized to the temperature T_{H^+}:

$$T_{\mathrm{H}^+} = T_{\mathrm{D}^+}(1 - \exp(-t/\tau_{\mathrm{E}}^{\mathrm{H}^+\mathrm{D}^+})), \qquad (5)$$

where $\tau_{\mathrm{E}}^{\mathrm{H}^+\mathrm{D}^+}$ is the ion energy exchange time, $\tau_{\mathrm{E}}^{\mathrm{H}^+\mathrm{D}^+} = \tau_{\mathrm{i}}((m_{\mathrm{i}} + m_{\mathrm{p}})^2/2m_{\mathrm{i}}m_{\mathrm{p}})$.

In the case of the RF power of 10 kW, the RF pulse time is 0.3 s, the above estimation gives T_{H}^+ about 70 eV and n_{H}^+ about $0.35 \times 10^{17}\ \mathrm{m}^{-3}$. This estimation method is implemented into the DEGAS 2 background calculation together with other parameter input which are directly from the experiment.

3.2. Atomic physics and plasma wall interaction included

The flux of ions which bombard the limiter surface can be evaluated according the sheath theory. Here we just assume a simple sheath, then the energy E of the ions bombard the walls can be expressed as:

$$E = E_{\mathrm{i}} + 3T_{\mathrm{e}}$$

and the ion flux to be $\phi_{\mathrm{i}} = 0.5n_{\mathrm{i}}\mathrm{Cs}_i$, where Cs_i is the ith ion's acoustic speed.

The reflection and desorption from the walls and limiter surfaces when ions or atoms bombard, are included in the modeling while the sputtering is not considered. We just use the data already provided in the DEGAS 2 package in which the data is collected from various combination of databases. The ion and neutrals induced wall desorption was assumed to be a puff source from the walls. At nearby of the limiter, the neutral density would be higher in comparison with that at the other places, the line emission would be dominated by emission from the reflected particles. Due to no line observation at the place other than the limiters, it is very difficult to model and compare this kind of induced desorption.

The ionization and charge exchange processes of neutral atoms are considered and the major processes of hydrogen molecules are included in the calculation. The data is mainly from Janev's book [3] except that the hydrogen charge exchange is from [4].

3.3. Modeling results

Fig. 4 shows the modeled Dα and Hα profiles. For the comparison with the experiment, Fig. 5 shows the convoluted profile of the modeled Balmer profiles together with that from the experiment. A general agreement was obtained within the scope of the experiment resolution. This agreement verified the estimation of the hydrogen ion density and energy. The modeled spectrum profile shows the emission is dominantly contributed by the atoms in the energy range of 10–20 eV. A discrepancy exists especially at short wave length region which are mainly Dα emission. The discrepancy indicates the

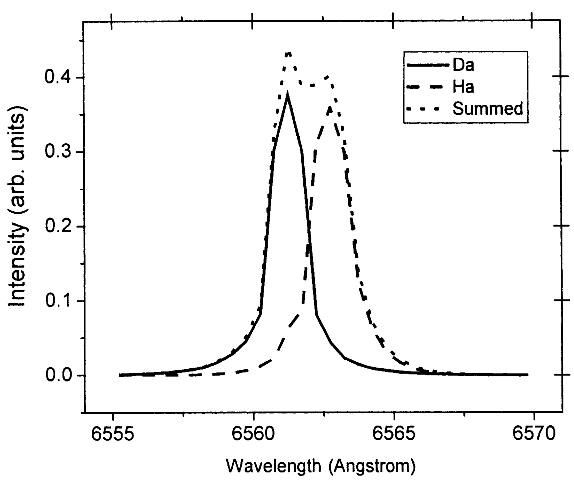

Fig. 4. Modeled Dα and Hα emission profile.

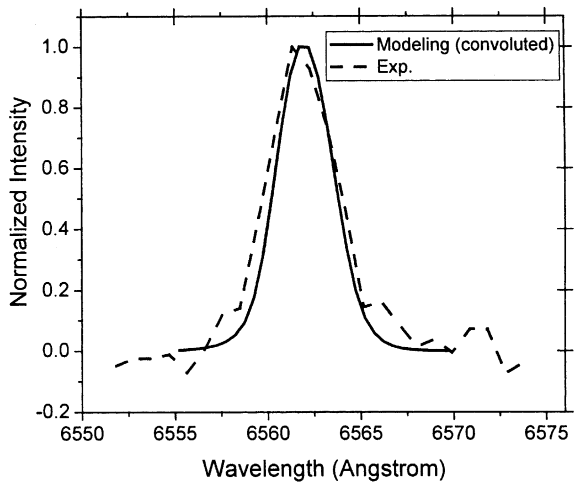

Fig. 5. The comparison of the modeled profile with experiment.

underestimation of the energy of deuterium atoms in the modeling is a little less than it is in the real case. There are various reasons that might cause the underestimation. One might be that the high energy tail of deuterium ions are not considered. There is also the possibility that the energy reflection ratio is underestimated in the modeling. To elucidate the problem clearly, an optical spectroscopy in higher resolution is required providing a possibility to have a more comprehensive modeling.

4. Discussion and summary

From the modeled profile, the Balmer line emission are mainly from the atoms in the energy group of 10–20 eV. The modeled spectrum details show the contribution is mainly from the reflected particles and charge exchange. Due to the low electron energy and density, these high energy neutral atoms could not easily be ionized and high amount of them finally reach the pumping area after several reflections from the walls or collisions with the background particles. Moreover, these neutral atoms could give rise to the induced wall desorption and they could not easily be trapped by the wall surface or pass through the walls due to their medium energy. These mechanisms also qualitatively explain that the saturation of the hydrogen removing rate with the ICRF input power. When the input power is greater than a certain value, i.e, 30 kW in HT-7 wall conditioning, which results in higher electron energy and density. There are two aspects. One is that higher energy of hydrogen neutrals resulting from higher plasma, leads to easy removal of the neutrals and possibly leads to a higher ion/neutral induced wall desorption. The other aspect is that higher plasma temperature and density result in easier ionization of neutrals before they are pumped out. This would make it difficult for the hydrogen removal. Thus the hydrogen removing rate would have a saturation point with the input RF power. In HT-7, this point is at around 10 kW.

In conclusion, high amount of the hydrogen atoms in the medium energy range of 10–20 eV during the phase of wall conditioning may be the main reason for the easier hydrogen removal. In HT-7, this could be achieved by using the ICRF power at about 10 kW with the deuterium working gas at the pressure of about 0.01 Pa.

Acknowledgement

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References

[1] J.K. Xie et al., J. Nucl. Mater. 290–293 (2001).
[2] D. Stotler, C. Karney, Contribut. Plasma Phys. 34 (2/3) (1994) 392.
[3] R.K. Janev et al., Elementary Processes in Hydrogen–Helium Plasmas, Springer Series on Atomic and Plasmas, 1987.
[4] R.K. Janev, J.J. Smith, Nucl. Fusion 4 (1993).