§79. Optimization of ICRF Heating

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In the 15th experiment cycle (2011) another pair of ICRF heating antennas was installed in LHD. They are arrayed in the poloidal direction. The ICRF heating experiment was carried out using the poloidal array (PA) antennas and HAS (handshake) antennas. An RF power with the frequency of 38.5MHz was supplied to each antenna from the each RF generator. The ratio of H/(H+He) has been routinely measured with visible lines as their particle sources. In this cycle it was found that the measured H/(H+He) agreed with the $^{+}H/(^{+}H+^{2+}He)$ obtained in the NBI plasma with CXR method [1]. Therefore H/(H+He) became an important key parameter to examine the ICRF heating characteristics. A minority heating method for the ICRF heating was employed: The minority ion was a hydrogen ion with the He ion as the majority. The magnetic strength on the plasma axis, i.e., R_{ax}=3.6m was B=2.75T.

The confinement time has a scaling of ISS04,

$$\tau_E \propto n_e^{0.54} P_{RF}^{-0.61}$$

The dependence of $W_p/P_{RF}^{0.39}$ on n_e is shown in Fig.1 using many ICRF heated plasma discharges. It is found that the envelope of plotted data has a curve of $n_e^{0.54}$ shown with dotted line,

$$\frac{W_p}{P_{RF}^{0.39}} \propto n_e^{0.54}$$

Degradations are found in the lower density ($n_e<1x10^{19}m^{-3}$) and higher density ($n_e<2.5x10^{19}m^{-3}$). In the lower density it is easily interpreted that the degradation was caused with the lower heating efficiency η. The ICRF heated plasma was fueled with only He gas puffing, but the hydrogen is fueled with recycling from the vacuum wall. Generally the H/(H+He) becomes larger in the lower density and η is lower. On the other hand in the higher density the H/(H+He) becomes lower and η becomes higher. In the higher density a series of the experiment was carried out changing H/(H+He) as shown in Fig.2. Here it was supposed that the energy confinement time τ_E dependsed on C_{eff} and η in the following equation,

$$\tau_E \propto C_{eff}(H/(H+He)) n_e^{0.54} (\eta(H+(H+He))P_{RF})^{-0.61}$$

Here it was also supposed that the C_{eff} and η depended on the H/(H+He). The C_{eff} shows an ICRF heating quality and depends on where the ICRF heating occurs. The plasma stored energy W_p is

$$W_p = \eta P_{RF}\tau_E \propto C_{eff} n_e^{0.54} (\eta P_{RF})^{0.39}$$

Therefore $C_{eff}x\eta^{0.39}$ in arbitrary unit is plotted on H/(H+He) using the equation of

$$C_{eff} \times \eta^{0.39} \propto \frac{W_p}{n_e^{0.54} P_{RF}^{0.39}}$$

The heating efficiency η was evaluated using the measured energy confinement, the ICRF injected power and the plasma stored energy in each plasma discharge. As seen in Fig.2 the $C_{eff}x\eta^{0.39}$ increases with but the heating efficiency η decreases with H/(H+He). It is found that the $C_{eff}x\eta^{0.39}$ increases from 1.0 to 1.4 and η decreases from 0.75 to 0.4 in the range of 10% to 16% of H/(H+He). Therefore C_{eff} is calculated from those values, i.e., $C_{eff}x\eta^{0.39}$ and η. Then the calculated C_{eff} increases from 1.2 to 1.8 by 50% in the same range of H/(H+He) as also seen in Fig.2. It can be summarized that the better C_{eff} is achieved at H/(H+He)=16%, and on the other hand the higher heating efficiency η is achieved at H/(H+He)=10%. Generally the higher heating efficiency is achieved in the lower minority ratio, because the position (where the fraction of the left-hand circularized RF electric field component is maximized) accesses to the ion cyclotron resonance layer. Then more low energy ions can be accelerated with this RF field via. cyclotron damping. On the other hand it is found that the C_{eff} is maximized at H/(H+He)=16% when the position with the maximized left-hand circularized RF electric field is located on the magnetic axis in this experiment condition, i.e., f=38.5MHz, R_{ax}=3.6m was B=2.75T. It is proposed that the optimized ICRF heating is realized, when the position with the maximized left-hand circularized RF electric field is located on the magnetic axis, when the low minority ratio such as H/(H+He)~10%.

[1] K.Ida, private communication.

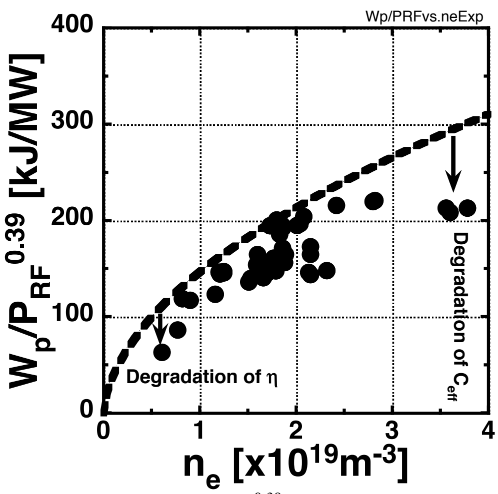

Fig.1 Dependence of $Wp/P_{RF}^{0.39}$ on the electron density n_e.

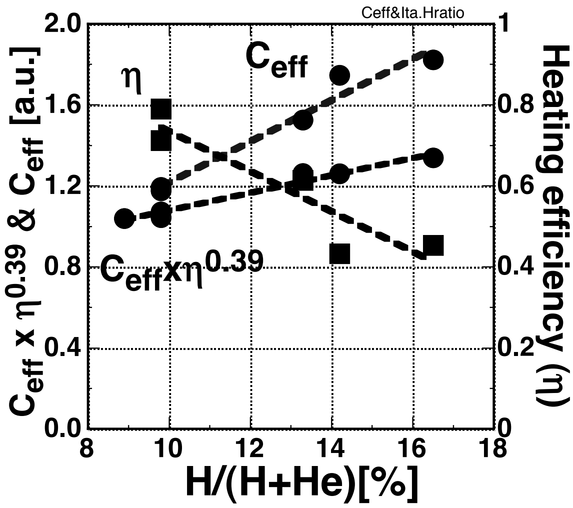

Fig.2 Dependence of C_{eff} and η on H/(H+He).