§8. New Global Confinement Scaling for High-Density LHD Plasmas

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Systematic density and power scan experiment has been carried out at various magnetic field strength, to investigate the temperature and magnetic field dependences of the thermal diffusivity. In the experiment discussed here, B_0 is varied as 1.0, 1.5, and 2.0 T, while the magnetic configuration is fixed to R_{ax} = 3.6 m. Plasmas are heated by negative-ion based neutral beam (NB) injection. One or two tangential beam lines are used in the B_0 scan experiment and the total heating power is varied from 2 to 5 MW. The density is scanned by hydrogen gas puffing.

In Fig. 1, depicted are the effective electron thermal diffusivity, χ_e^{eff}, versus T_e, obtained after the B_0 scan experiment. The weak ($\chi_e^{eff} \propto T_e^{0.5}$) and gyro-Bohm like ($\chi_e^{eff} \propto T_e^{1.5}$) temperature dependences are recognized for each datasets at different B_0. To estimate the inflection temperature, T_{e1}, where the temperature dependence of χ_e^{eff} changes from $\chi_e^{eff} \propto T_e^{0.5}$ to $\chi_e^{eff} \propto T_e^{1.5}$, a set of models below is assumed;

$$\chi_e^{eff} = C_1\, T_e^{0.5} / B_0^{\alpha}\ (T_e \le T_{e1}), \tag{1}$$

$$\chi_e^{eff} = C_2\, T_e^{1.5} / B_0^{2}\ (T_e > T_{e1}). \tag{2}$$

Below the inflection temperature, χ_e^{eff} increases with $C_1\, T_e^{0.5}$ and decreases with an unknown B_0 dependence of an index α. Note that α = 1.0±0.2 was obtained in the former study [1]. Above the inflection temperature, we simply assume the gyro-Bohm model with a factor C_2. Three parameters of C_1, C_2 and α are determined at each ρ (= r/a), to give the minimum standard deviation, σ, of the experimental χ_e^{eff} compared with the model. From the fitting results, we conclude α = 1.2±0.1, which is consistent with the former result of α = 1.0±0.2, while the ambiguity is reduced. Examples of the fitting are also shown in Fig. 1, by solid and broken lines.

To obtain a dimensionally correct expression, another dependence on the minor radius of $\chi_e^{eff} \propto a^{-0.5}$ should be introduced to Eq. (1) as below;

$$\chi_e^{eff} \propto (T_e/a)^{0.5}\ /\ B_0^{1.2}. \tag{3}$$

Assuming $\tau_E^{HD} \propto a^2/\chi_e^{eff}$, Eq. (3) is transformed to

$$\tau_E^{HD} \propto P_{tot}^{-1/3}\ \langle n_e\rangle^{1/3}\ B_0^{4/5}\ a^{7/3}\ R^{1/3}. \tag{4}$$

where P_{tot}, $\langle n_e\rangle$, and R denote the total heating power, the volume-averaged electron density, and the plasma major radius, respectively.

According to Eq. (4), the plasma stored energy should be expressed by the HD (High-Density) scaling below;

$$W_p^{HD} = C\ \langle P_{dep}\rangle^{2/3}\ \langle n_e\rangle^{1/3}\ B_0^{4/5}\ a_{eff}^{7/3}\ R_{ax}^{1/3}, \tag{5}$$

where units of W_p^{HD}, $\langle P_{dep}\rangle$, $\langle n_e\rangle$, B_0, a_{eff}, and R_{ax} are kJ, MW, $10^{19}m^{-3}$, T, m, and m, respectively. To include the NB deposition profile effect, which becomes shallower in the high-density regime, the volume average of the NB deposition profile, $\langle P_{dep}\rangle$, is adopted as an index of the heating power. An effective minor radius, a_{eff} is defined by a product of a and ρ_{100eV}, where ρ_{100eV} is the average of ρ where T_e ranges from 50 to 150 eV. This T_e range is chosen because the reliability of our Thomson scattering system is assured at T_e > 30 eV. In our database, the effective minor radius is distributing within roughly ±5% of 0.64 m, which corresponds to a in the vacuum configuration. As for the major radius, we adopt R_{ax} for simplicity. This scaling is compared with the datasets of B_0 scan experiment in Fig. 2. The factor C = 140 is determined by the least square method using this data. As seen in the figure, the HD scaling well matches with the experiment.

Compared with ISS95 ($\tau_E^{ISS95} \propto n^{0.51} P^{-0.59}$), the HD scaling has weaker density dependence ($\tau_E^{HD} \propto n^{1/3}$). However, it should be noted that the HD scaling is still favorable since the density dependence is positive and, especially, the power degradation is weak ($\tau_E^{HD} \propto P^{-1/3}$).

Reference

[1] J. Miyazawa *et al.*, Plasma Phys. Control. Fusion **47**, 801 (2005).

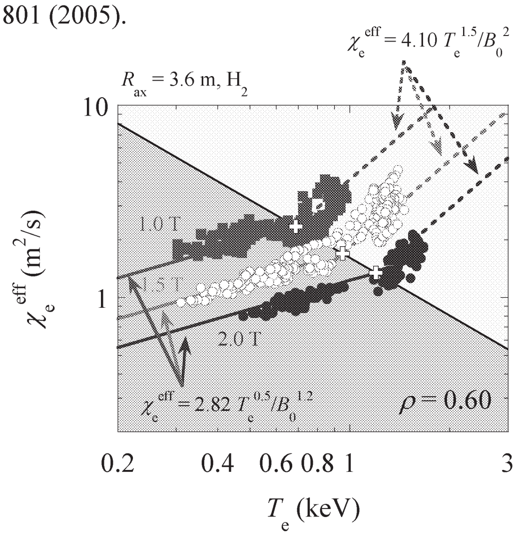

Fig. 1. T_e dependence of χ_e^{eff} at various B_0. Solid and broken lines show fitting results with α = 1.2.

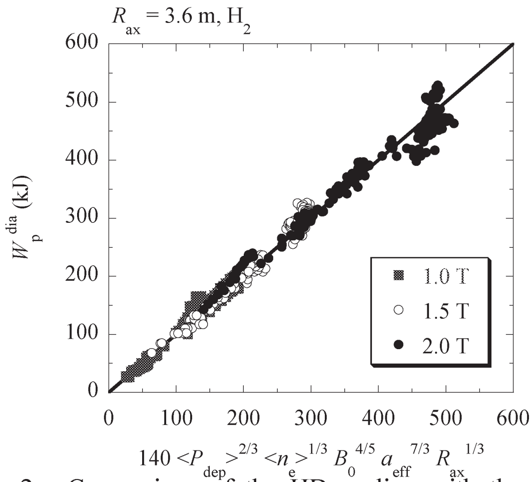

Fig. 2. Comparison of the HD scaling with the data from the B_0 scan experiment.