§2. Parameter Dependence of the Fusion Triple Product in Annealing Discharges

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Parameter dependence of the fusion triple product, $n_{e0}\tau_E T_{e0}$, has been experimentally studied for high-density internal diffusion barrier (IDB) plasmas in LHD, where n_{e0}, τ_E and T_{e0} are the central electron density, the energy confinement time, and the central electron temperature, respectively. Especially, reduction of the heating power, P_{tot}, is effective in increasing $n_{e0}\tau_E T_{e0}$, which we call “annealing operation” on the analogy of metallurgy. Typical example of the annealing operation is shown in Fig. 1. Results of the density and heating power scan experiment suggest that the highest $n_{e0}\tau_E T_{e0}$ at a given experimental condition is in inverse proportion to $P_{tot}^{0.5}$, as indicated by the upper envelope of the data plotted in Fig. 2.

In LHD, the maximum density achievable at a given experimental condition is defined by $n_e^{edge} = n_c^{Sudo}$, where n_e^{edge} is the edge density at the radial position where $T_e = 100 \pm 50$ eV, and n_c^{Sudo} is the conventional Sudo density limit scaling that is proportional to $P_{tot}^{0.5}$. Since the high-density operation is preferable for achieving $n_{e0}\tau_E T_{e0}$, the ratio n_e^{edge}/n_c^{Sudo} should be increased as large as possible (< 1 to avoid radiative collapse). According to the experimental results, $n_{e0}\tau_E T_{e0}$ is proportional to both n_e^{edge}/n_c^{Sudo} and the peaking factor of the density profile, as far as the parabolic temperature profile is kept. Here, let us define the density peaking factor by n_{e0}/n_e^{edge}, then $n_{e0}\tau_E T_{e0} \propto (n_{e0}/n_e^{edge})\ (n_e^{edge}/n_c^{Sudo}) \propto (n_{e0}/n_c^{Sudo})$. This relation is shown by the thick line in Fig. 3. The ratio of $n_{e0}\tau_E T_{e0}/(n_{e0}/n_c^{Sudo})$ is small when the temperature profile is flat or hollow, which causes the large scatter below the line in Fig. 3. The highest $n_{e0}\tau_E T_{e0}$ so far achieved by the annealing operation ($P_{tot} \neq 0$) is 5.1×10^{19} m^{-3}·s·keV, where $n_{e0} \sim 4.0 \times 10^{20}$ m^{-3}, $\tau_E \sim 0.23$ s, and $T_{e0} \sim 0.55$ keV.

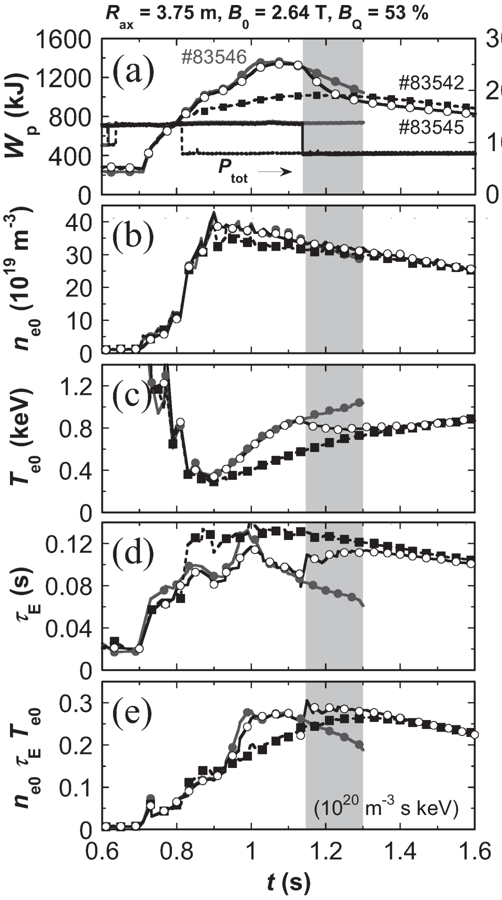

Fig. 1. Typical waveforms in an annealing discharge (#83545, open circles), compared with high power (#83546, filled circles) and low power (#83542, filled squares) heating discharges. (a) The diamagnetic plasma stored energy, W_p, and the total heating power, P_{tot}, (b) the central electron density, n_{e0}, (c) the central electron temperature, T_{e0}, (d) the energy confinement time, τ_E, and (e) the fusion triple product, $n_{e0}\tau_E T_{e0}$, are shown from top to bottom.

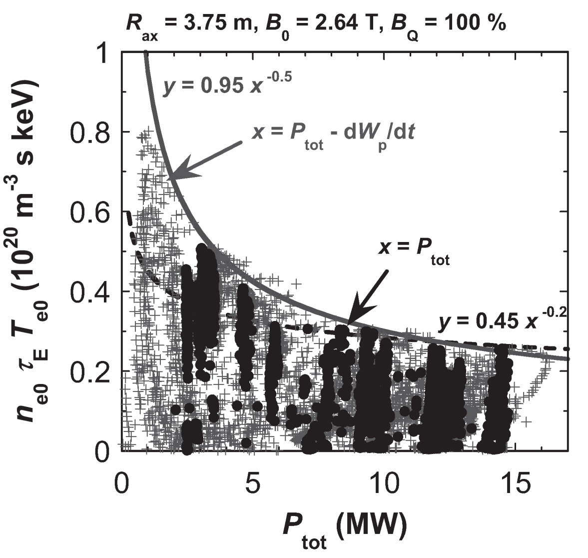

Fig. 2. $n_{e0}\tau_E T_{e0}$ versus P_{tot} (filled circles), or P_{tot} - dW_p/dt (crosses).

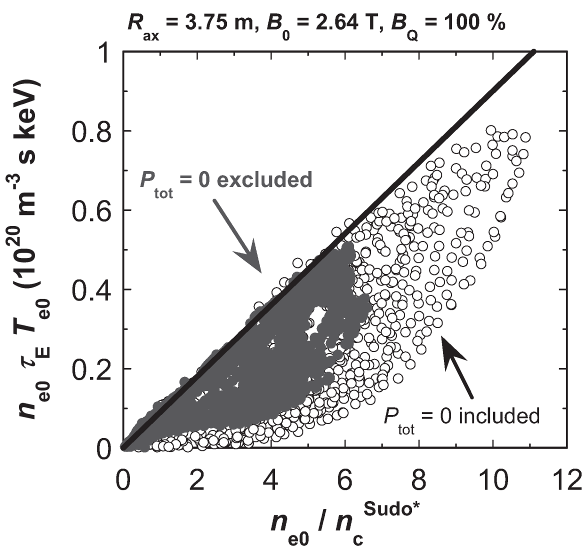

Fig. 3. $n_{e0}\tau_E T_{e0}$ versus n_{e0}/n_c^{Sudo*}, where filled circles denote $P_{tot} \neq 0$.