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A power balance model of the L-mode density limit in fusion plasmas

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Density limit (DL) is ubiquitous in magnetic confinement fusion devices, and several processes can trigger this phenomenon. In particular, DL can take place as a radiation limit.

In this regard, a 1D cylindrical power-balance model, matching fairly well experiments in the L-mode tokamak, in the reversed field pinch (RFP), and in the stellarator, derives a DL as bound of the equilibrium states characterized by realistic temperature profiles, i.e. with small values only at the edge, in the presence of radiation losses from impurities and edge neutrals [1, 2]. In this model the DL scaling laws are obtained by exploiting just two equations: i) 1D single-fluids steady-state heat transport, ii) on-axis ohm's law with Spitzer resistivity, which is taken in a suitable limit for the stellarator. No hypothesis for the energy transport is made in this model. The generality of the model stems from the minimal 1D physics involved and from taking integrals of equation i), hence smoothing out the profile peculiarities of the different configurations.

The model predicts a Sudo-like scaling law for the Stellarator, with dependences on the heating power *P* and the toroidal field. Instead, the same Greenwald-like scaling law for the tokamak and the RFP is obtained: this expression features a quasi-linear dependence on the Greenwald parameter n_G for the pure ohmic heating, a mixed dependence $\sim(P/\pi a^2)^{0.5} n_G^{0.5}$ for the additionally heated case, and a tenuous dependence on the energy confinement time $\tau_E^{-1/9}$, giving almost the same quantitative prediction for the two configurations. All these scaling laws predict also dependences on the impurity concentration, the edge neutral concentrations, as well as dependences on integral shape factors.

As far as the tokamak and the RFP are concerned, our analysis contradicts the widespread vision of a DL representable by the single parameter n_G, since the estimates obtained by the proposed model better compare to the experimental data, as can be seen in figure 1.

References

[1] P. Zanca et al, Nucl. Fusion 57 (2017) 056010

[2] P. Zanca et al, Nucl. Fusion 59 (2019) 126011

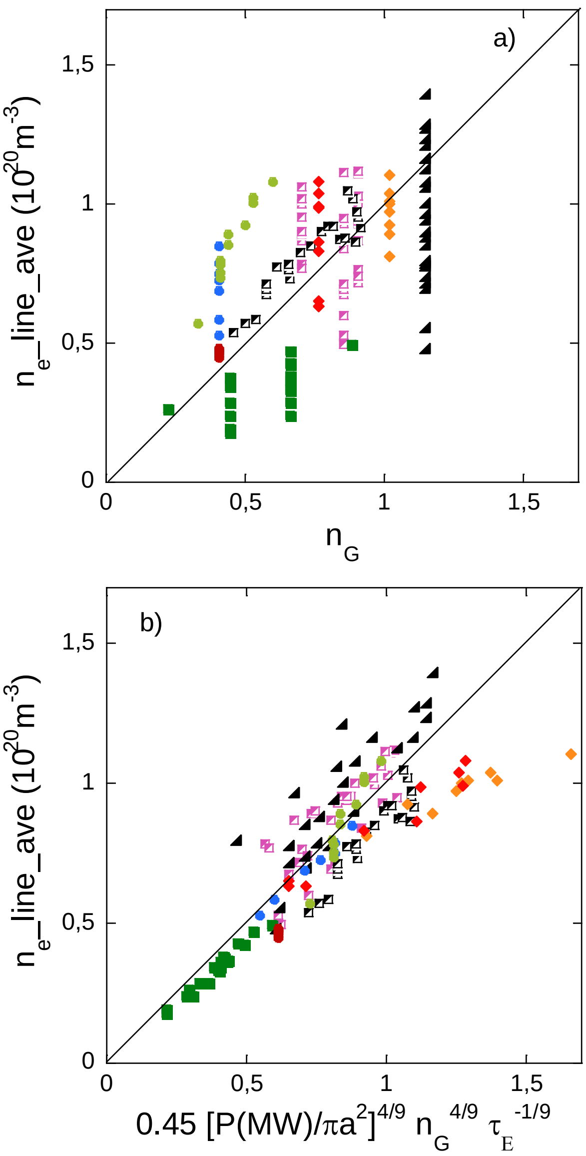

Figure 1. Maximum published line-average densities obtained in several L-mode NBI tokamak experiments. They are plotted vs. n_G in (a), and vs the proposed model in (b).