Theory-based Scaling of Energy Confinement Time for Future Reactor Design*

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A theory-based scaling of thermal energy confinement time has been derived based on TGLF and EPED in burning plasma conditions for future reactor design. The simulation dataset consists of a massive number of predictive IPS-FASTRAN [1] simulations, self-consistent with core transport (TGLF), edge pedestal (EPED), alpha heating, and MHD equilibrium (EFIT). The DAKOTA-enabled Integrated Plasma Simulator (IPS) framework generates the multi-dimensional parametric scan with random sampling of major radius ($4 < R < 8$ m), aspect ratio ($2.5 < R/a < 3.5$), elongation ($1.5 < \kappa < 2.0$), triangularity ($0.3 < \delta < 0.6$), toroidal magnetic field ($4 < B_T < 8$ T), plasma current ($3.5 < q_{95} < 8.5$), line average density ($0.6 < n_e / n_{GW} < 1$), and heating power ($20 < P_{inj} < 150$ MW). Each IPS-FASTRAN simulation in the scan is largely theory-based except a model specification of the heating and plasma current profiles. A Gaussian form of the heating profile is employed with the ratio of electron and ion heating as an additional scan parameter ($0.0 < P_e/P_i < 1.0$) to take into account difference in the heating and current drive actuators such as neutral beam injection and RF heating. The model current profile is a combination of the bootstrap current in the edge pedestal determined by EPED and the core current profile parameterized to make variation of minimum q (q_{min}), the minimum q location (ρ_{qmin}), and the average magnetic shear (q_0-q_{min}) in the core. For the ITER baseline H-mode type current profile with q_0~1.0, the TGLF/EPED energy confinement time scales as

$$\tau_{TGLF/EPED} = 0.098\, I_p^{0.80} B_T^{0.28} n_e^{0.42} P^{-0.71} R^{2.1} \kappa^{0.81} \varepsilon^{0.90},$$

in a dimensionally homogenous form, showing ~ +/-10% difference from the ITER H-mode confinement scaling of the multi-machine experimental database [2] for the data set generated in burning plasma condtion. The exponent of the log-linear scaling expression reveals different dependency on the engineering variables, for example stronger dependency on B_T. Substantial improvement of energy confinement time is predicted for the broader current profile, $\tau_{TGLF/EPED} \sim (1+0.45\rho_{qmin}^{1.2})$, identifying an optimization path to AT steady-state reactor. An example of the system code application will be presented.

[1] Park et al, Phys. Plasmas **25**, 012506 (2018) [2] McDonald et al, Nucl. Fusion **47**, 147 (2007)

*This work was supported in part by US Department of Energy under DE-AC05-00OR22725, DE-FC02-04ER54698, DE-FG02-95ER54309, and DE-SC0012656