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

J.M. Park\textsuperscript{1}, G. Staebler\textsuperscript{2}, P.B. Snyder\textsuperscript{2}, C.C. Petty\textsuperscript{2}, D.L. Green\textsuperscript{1}, K.J. Law\textsuperscript{1}

\textsuperscript{1}Oak Ridge National Laboratory, Oak Ridge, TN, USA
\textsuperscript{2}General Atomics, PO Box 85608, San Diego, CA, USA

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 \cite{Park2018} 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 ($20 < P_{\text{inj}} < 150$ 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 ($q_{\text{min}}$), the minimum q location ($r_{q_{\text{min}}}$), and the average magnetic shear ($q_0-q_{\text{min}}$) in the core. For the ITER baseline H-mode type current profile with $q_0\sim 1.0$, the TGLF/EPED energy confinement time scales as

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

in a dimensionally homogenous form, showing $\sim +/-10\%$ difference from the ITER H-mode confinement scaling of the multi-machine experimental database \cite{McDonald2007} for the data set generated in burning plasma condition. 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, $\tau_{\text{TGLF/EPED}} \sim (1+0.45\rho_{q_{\text{min}}^{1.2}})$, identifying an optimization path to AT steady-state reactor. An example of the system code application will be presented.

\cite{Park2018, McDonald2007}

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