On the relationship between the H-mode separatrix density and engineering parameters across multiple tokamaks: physics-based models, regression, and extrapolations to next-step devices

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The electron density at the separatrix (ne,sep) plays a central role in balancing energy confinement, detachment achievement, and ELM suppression in tokamaks, thereby influencing core-edge integration. To study what determines this key parameter, a database of H-mode separatrix density measurements from the Alcator C-Mod, ASDEX Upgrade, and JET tokamaks has been assembled using a consistent analysis method across all devices. This dataset is used to assess the validity of a physics-based predictive model and to derive a regression scaling expression for ne,sep , both requiring only engineering parameters as input. The theory-based expression is obtained by coupling two-point model equations with simple geometrical relations, and successfully reproduces experimental measurements across all three devices, with the exception of a common multiplicative constant. The regression confirms similar parameter dependencies, revealing a positive dependence on divertor neutral pressure and the ratio of the power entering the scrape-off layer to the major radius, a negative dependence on the toroidal magnetic field and minor radius, and no significant dependence on the plasma current. Both the resulting scaling and theory-based expressions predict ne,sep within a factor of 1.5 across the three machines, and provide projections to next-step devices (ITER, SPARC, DTT, JT-60SA and COMPASS-U) that are in agreement with available SOLPS simulations.