Neoclassical Toroidal Viscosity from Non-Axisymmetric Magnetic Fields Allows ELM-free, Quiescent H-Mode Operation in DIII-D under Reactor-relevant Conditions*

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Application of static, non-axisymmetric magnetic fields (NAMFs) to high β DIII-D plasmas allows sustained operation with an ELM-free, quiescent H-mode (QH-mode) edge under reactor-relevant conditions with torque from neutral beam injection (NBI) in the co-current direction. QH-mode is an ideal plasma for next step devices, exhibiting H-mode confinement levels while operating without ELMs at constant density and radiated power. The key to QH-mode operation is the presence of an edge-localized, electromagnetic mode, the edge harmonic oscillation (EHO), which increases the edge particle transport, allowing the plasma to reach a transport steady state at edge parameters just below the peeling-ballooning, ELM stability limit. Peeling-ballooning theory suggests and previous studies confirm that QH-mode operation requires sufficient radial shear in the toroidal rotation near the plasma edge. In most past experiments, this rotation shear was produced by torque from counter-directed NBI. In recent experiments, co-NBI torque was overcome by the counter torque due to neoclassical toroidal viscosity (NTV) produced by the applied NAMFs. Theoretical predictions of this NTV torque show promising levels of agreement with experimental measurements. The application of the NAMFs does not degrade the global energy confinement of the plasma; indeed, at the lower rotation achieved with balanced torque, the energy confinement times actually improve. By utilizing the physics of NTV from NAMFs, these new results open a path for QH-mode utilization in self-heated, burning plasmas, where toroidal momentum input from NBI will be small or absent.

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