Topic: EX-C

The Dependence of H-mode Energy Confinement and Transport on Collisionality in NSTX

S.M. Kaye[1], S. Gerhardt[1], R. Maingi[2], R. E. Bell[1], A. Diallo[1], W. Guttenfelder[1], B.P. LeBlanc[1] (email: skaye@pppl.gov)

[1] Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543
[2] Oak Ridge National Laboratory, Oak Ridge, TN 37831

Initial H-mode energy confinement scaling experiments in the high-power, low aspect ratio National Spherical Torus Experiment (NSTX) exhibited confinement dependences that were quite different than those on conventional aspect ratio devices, the latter being described by the ITER98y,2 scaling[1]. The thermal energy confinement was found to scale as $I_p^{0.4}B_T^{0.9}$, which translated into a strong increase in confinement with decreasing collisionality[2] ($\tau_E \sim \nu_*^{-1}$). These plasmas were run with wall conditioning of boronization and between-shot Helium Glow Discharge Cleaning. The strong improvement of energy confinement with decreasing collisionality could potentially influence the design and construction of a Spherical Tokamak (ST)-based Fusion Nuclear Science Facility[3,4], which will operate at collisionalities at least one order of magnitude less than the operating range of NSTX in this parameter. Thus, it is important to test this collisionality dependence at lower collisionalities and to understand the physics behind this scaling.

Factors of two to three lower collisionalities were obtained in more recent NSTX H-mode plasmas in which between-shot evaporation of lithium was employed for vessel wall conditioning. These lithiated discharges revealed thermal energy confinement scalings much closer to the ITER98y,2 scaling, with $\tau_E \sim I_p^{0.95}B_T^{-0.15}$. The question, then, is whether the unlithiated and lithiated discharges are fundamentally different, or whether the different scalings with engineering parameters can somehow be reconciled. This was studied by examining both sets of discharges by holding one engineering parameter fixed while the other was varied.

At fixed toroidal field of 0.53 T, the impurity density decreased by about a factor of two, and thus Z_{eff} decreased by about 30% with increasing plasma current (from 0.7 to 1.25 MA) for both the lithiated and unlithiated discharges. Because of the decreasing q with increasing I_p also, the electron collisionality at the half radius decreased by a factor of three for both datasets over this current range, resulting in a drop of confinement with increasing ν_* at this fixed B_T. At fixed I_p of 0.7-0.8 MA , the change in impurity density and Z_{eff} was minimal over the range of B_T (0.3 to 0.55 T) for the two discharge sets, and it was found that the collisionality variation was controlled primarily by the electron temperature profile. For the unlithiated discharges, the T_e profile broadened by over 30% with increasing B_T, while that for the lithiated discharges it remained about the same. This led to a decrease in ν_* with B_T for unlithiated discharges, but an increase in ν_* for the lithiated ones, the latter dependence owing to the increase in B_T and thus q. The energy confinement time was seen to decrease with collisionality for the unlithiated discharges, but remain constant with ν_* for the lithiated ones. For both the fixed B_T and fixed I_p cases, parameters such as β_T and q also varied across the range of collisionality.

The final set of data examined came from a set where I_p and B_T were held constant and the amount of between-shot lithium was varied from 0 to 1000 mg[5]. For this set of data, the T_e profile was found to broaden considerably with increasing amounts of lithium deposition, resulting in a factor of four reduction in collisionality over this range, and the thermal energy confinement increased from 25 to 90 ms and the electron energy confinement time increased from 20 to over 100 ms. The increase in electron confinement was driven by a sharp reduction in the electron thermal diffusivity in the outer region of the plasma, dropping from near 20 m^2/s at r/a~0.7 with no deposited lithium to a value of near 0.7 m^2/s at the highest lithium deposition level (Fig. 1). These reductions correspond also to a decrease in χ_e with respect to $\chi_{gyroBohm}$.

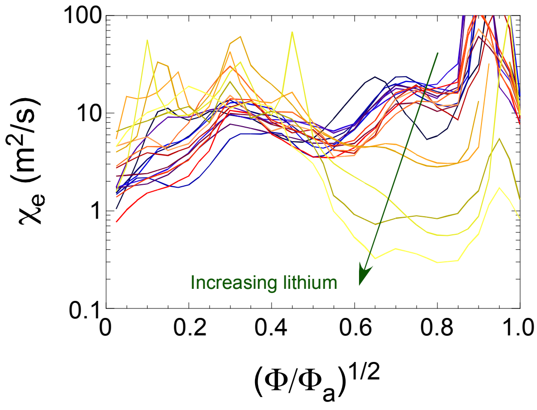

Fig. 1 Electron thermal diffusivity for the set of discharges in the lithium deposition scan.

In order to assess the dependence of confinement on collisionality, data from the various scans were constrained to narrow ranges of q and in order to isolate the ν_* variation. The result is shown in Fig. 2 where it is seen that the normalized confinement of both the lithiated and unlithiated discharges are well-ordered by collisionality, which unifies the scaling of discharges with both types of conditioning. The scaling of the normalized confinement time remains quite strong and favorable as collisionality decreases.

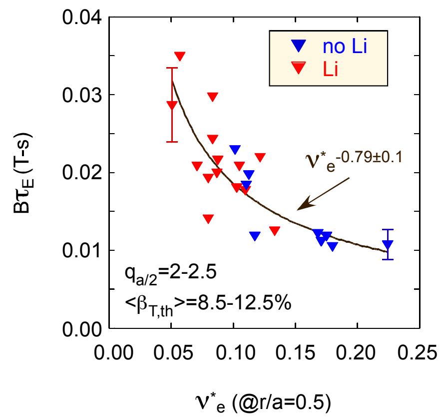

Fig. 1 Electron thermal diffusivity for the set of discharges in the lithium deposition scan.

The underlying physics responsible for this strong scaling is presently under investigation. Non-linear gyrokinetic calculations of the unlithiated discharges reveal unstable microtearing modes whose transport levels and scaling with collisionality are consistent with those inferred from experiment. Linear gyrokinetic calculations indicated that both microtearing and ETG modes become more unstable at the higher collisionality for the lithiated discharges. Studies to tie these gyrokinetic calculations to both measured turbulence and inferred transport are underway.

This work was supported in part by U.S. DOE Contract DE-AC02-09CH11466.

References:

[1] ITER Physics Basis, Nuclear Fusion **39** (1999) 2137.
[2] Kaye, S.M. et al., Nuclear Fusion **46** (2007) 499.
[3] Menard, J.E. et al., Nuclear Fusion **51** (2011) 103014.
[4] Peng, Y.K.M. et al., Fusion Science and Technology **60** (2011) 441.
[5] Maingi, R. et al., Phys. Rev. Lett. **107** (2011) 145004.