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DEPENDENCE OF HELIUM TRANSPORT ON PLASMA CURRENT AND ELM FREQUENCY IN H–MODE DISCHARGES IN DIII–D

by
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DEPENDENCE OF HELIUM TRANSPORT ON PLASMA CURRENT AND ELM FREQUENCY IN H-MODE DISCHARGES IN DIII-D*

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The removal of helium (He) ash from the plasma core with high efficiency to prevent dilution of the D-T fuel mixture is of utmost importance for future fusion devices, such as the International Thermonuclear Experimental Reactor (ITER). A variety of measurements in L–mode conditions have shown that the intrinsic level of helium transport from the core to the edge may be sufficient to prevent sufficient dilution (i.e., $\tau_{He}/\tau_E < 5$).[1-3] Preliminary measurements in biased-induced, limited H–mode discharges in TEXTOR suggest that the intrinsic helium transport properties may not be as favorable.[4] If this trend is shown also in diverted H–mode plasmas, then scenarios based on ELMing H–modes would be less desirable. To further establish the database on helium transport in H–mode conditions, recent studies on the DIII–D tokamak have focused on determining helium transport properties in H–mode conditions and the dependence of these properties on plasma current and ELM frequency.

EXPERIMENTAL SETUP AND METHOD

To simulate the presence of He ash in DIII–D, concentrations of 3%–10% He (relative to n_e) are puffed into the plasma during an otherwise steady-state phase of a H-mode discharge. This gas is generally introduced approximately 300–400 ms after the L-H transition, providing enough time for the density and temperature profiles to come to equilibrium. The gas puff does result in a slight increase in density and a slight decrease in plasma stored energy, but these changes are small enough (<10%) that, to first order, it can be assumed that the helium introduced by the gas puff evolves on a steady-state background plasma. For all of the experimental results listed below, a lower, single-null divertor configuration was used with toroidal magnetic field of 2.1 T, and a major radius of 1.67 m. The vacuum vessel walls were conditioned via boronization (conducted several operating days before these experiments) and via helium glow discharge cleaning (He GDC) between shots. Helium introduced to the vessel walls during He GDC resulted in an ambient helium level of approximately 3%–5 % (relative to n_e) during the plasma discharge.

The transport of the additional helium is monitored by measuring the temporal evolution of the helium density profile in the plasma core with a high resolution spectroscopy system, which uses the techniques of active charge-exchange recombination (CER) spectroscopy. The DIII–D CER system has 32 chords that span the entire cross section with excellent spatial resolution over the entire profile (3 cm in the core, 3 mm at the edge).[5] Helium density profiles are inferred from measurements of the intensities of the He II n=4–3 transition at 4685.68 Å. Absolute calibration of the sensitivity of each chord has been accomplished using standard calibration lamps and has been supplemented by two techniques involving (1) injection of the neutral beam into a gas-filled torus and (2) NBI into a pure He plasma. The helium density profiles inferred from each of these techniques are consistent, giving us confidence in our ability to deduce profiles from the measured data.

The helium transport coefficients are determined by matching the evolution of the helium density profile after the gas puff with simulations of the helium transport using the MIST code,[6] which has been upgraded to include non-circular geometry and ELM effects. This code solves the impurity diffusion equation for each ionization stage of a given impurity, explicitly including atomic physics effects. For example, the equation of interest for fully stripped helium (denoted by the subscript α) is:

$$\frac{\partial n_\alpha}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r\Gamma_\alpha) = \underbrace{-R_\alpha + I_{He^+} n_{He^+}}_{\text{Atomic Physics}} - \underbrace{\frac{n_\alpha}{\tau_\parallel}}_{\text{SOL}} + \underbrace{S_\alpha}_{\text{Source}}$$

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Here, n_α is the local helium density, R_α denotes the loss of He^{++} due to recombination, $I_{He^+} n_{He^+}$ is the ionization rate of He^+, $\tau_{\|}$ is the characteristic SOL loss time, and S_α represents any other source of helium. The helium particle flux Γ_α is given by the equation:

$$\Gamma_\alpha = -D_A^\alpha(r)\frac{\partial n_\alpha}{\partial r} + n_\alpha V_\alpha(r)$$

where D_A^α is the anomalous diffusion coefficient and V_α is the pinch velocity. In MIST, the pinch velocity is parameterized in terms of a pinch coefficient C_v in the following manner:

$$n_e V_\alpha(r) = C_v D_A^\alpha(r)\frac{\partial n_e}{\partial r}$$

Note that in an equilibrium state, the pinch coefficient has the form $C_v = L_{n_e}/L_{n_\alpha}$ where L_{n_e} and L_{n_α} are the electron and helium density gradient scale lengths, respectively. Hence, if the helium and electron density profiles have the same shape, $C_v = 1.0$, indicating no preferential accumulation or dilution of helium in the discharge.

In solving Eq (1), the transport coefficients are assumed to be time independent (i.e., it is assumed that the helium gas puff does not cause a perturbation in the helium transport characteristics of the discharge). Taking advantage of this assumption, the pinch coefficient C_v is first computed during a steady-state phase of the discharge in which the form $C_v = L_{n_e}/L_{n_\alpha}$ holds true. The value of D_A^α is then determined by finding the best comparison between the simulation and the measured profiles through iterative runs of the MIST code (with C_v held fixed at the value determined previously).

The most universal and possibly the most striking result found to date during these experiments is that the pinch coefficient C_v is very close to unity in all types of discharges studied to date (L–mode, ELM-free H–mode, ELMing H–mode). A comparison of the electron density profiles and the helium density profiles from CER during L–mode and ELMing H–mode is shown in Fig. 1. The lack of preferential accumulation of helium in any of these cases suggests that enrichment of helium in the core of ITER may not be a significant problem.

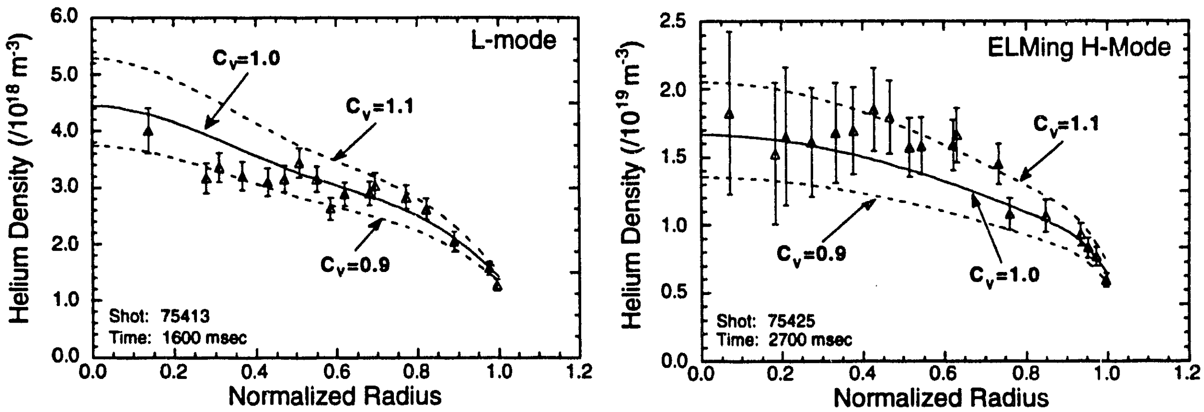

Fig. 1. Helium density profiles measured during L–mode and ELMing H–mode at $I_p = 1.6$ MA along with curves showing the sensitivity to variation of the pinch coefficient C_v. The curve corresponding to $C_v = 1.0$ is the normalized electron density profile inferred from Thomson scattering measurements.

Effect of Plasma Current on Helium Transport

The critical parameter in the assessment of helium buildup in a particular device is the ratio of the helium particle confinement time to the global energy confinement time, τ_{He}/τ_E. From empirical scaling studies of data from several tokamaks, it is well established that the global energy confinement time in H-mode discharges scales with the plasma current I_p as $\tau_E \propto I_p^{+n}$, where n is near unity.[7-8] To achieve a good balance between good energy confinement and the efficient removal of helium in a device like ITER (projected to have plasma currents 5–10 times those in present devices), it is desirable that the helium particle confinement time scale with plasma current in a similar manner. To assess the dependence of the helium transport coefficients on plasma current in DIII–D, dedicated helium transport studies were performed in discharges in which the plasma current was systematically scanned on successive discharges from 0.6 MA to 1.6 MA while holding the input power constant. In these particular shots, the change in plasma current resulted in an approximately two-fold increase in global energy confinement. MIST simulations indicate that the anomalous diffusion coefficient at the edge decreases by approximately a factor of two during the scan. Therefore, the magnitude of the parameter $1/\left(D_A^\alpha \tau_E\right) \propto \tau_{He}/\tau_E$ is constant with plasma current, suggesting that there is no net change in the trade off between good energy confinement and efficient removal of helium as the plasma current is increased.

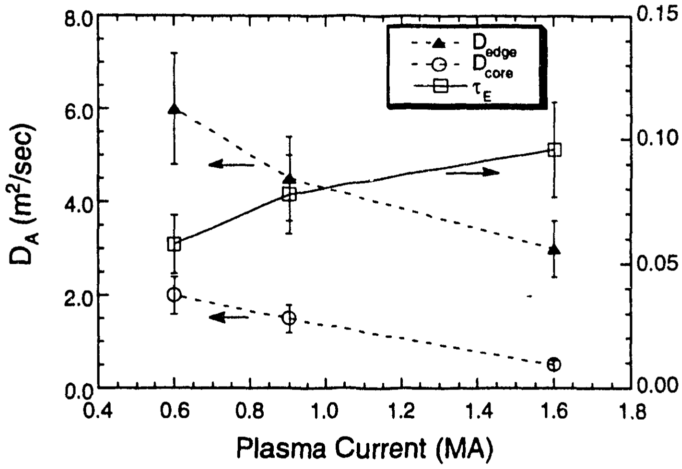

Fig. 2. Variation of diffusion coefficient and global energy confinement time with plasma current (P_{NBI} fixed at 10 MW).

Effect of ELMs on Helium Transport

Experiments from various tokamaks have consistently shown that quiescent H–mode discharges exhibit a strong accumulation of impurities throughout the lifetime of the discharge, eventually causing degradation in confinement.[9] This particular characteristic of quiescent H–mode discharges is undesirable in ITER where a similar accumulation of the intrinsic helium ash would eventually quench the burn. Further experiments have shown that impurity accumulation is not as prevalent in H–mode discharges with ELMs, resulting in discharges in which H–mode confinement can be maintained without degradation for long periods.[10-11] It is conjectured that the ELMs flush the impurities from the edge of the plasma, which in essence both increases the particle flux out of the plasma and reduces the effective recycling of the impurity. The latter is of particular importance for helium removal in ITER where recycled helium will constitute a large fraction of the helium inventory after a few seconds of the burn. This hypothesis is supported by measurements of the effect of giant ELMs on the helium density profile (see Fig. 3). From this figure, it is evident that a significant amount of helium is lost from the edge of the plasma during the ELM event. This purging of the edge is accompanied by a simultaneous increase of He^+ line emission in the divertor, suggesting a sharp increase in the divertor helium content. These observations taken together indicate that ELMs are efficient at flushing helium from the plasma edge to the divertor where, if pumping were available, the helium could be exhausted from the system readily.

ELMs also have an effect on global energy and particle confinement. Previous studies on DIII–D have shown that ELMs only slightly modify the global energy confinement time from similar quiescent H–mode discharges (on the order of 20%).[12] Since the ELMs are quite effective in removing helium from the edge of the plasma, it is conceivable that by controlling the ELM frequency, one may be able to lower τ_{He}/τ_E without compromising a great deal on energy confinement. To assess this issue in DIII–D, the ELM frequency was varied during successive discharges by changing the injection power while the plasma current was held fixed at 1.6 MA. In this manner, the ELM frequency was varied from 0 Hz (P_{NBI} = 5.0 MW) to 120 Hz (P_{NBI}= 12.5 MW). During this scan, the global energy confinement time decreases by a factor of 3 (due to the increase in injected power) while MIST analysis indicates an almost eight-fold increase in D_A^α. The decreasing trend of the parameter $\left(D_A^\alpha \tau_E\right)$ as the ELM frequency is increased (see Fig. 4) suggests that there is a favorable trend in the compromise between good energy confinement and the efficient removal of helium as the ELM frequency is increased. However, it should be noted that these trends can only be viewed as qualitative in nature, and it is not possible at present to determine from these data if the level of helium transport in H–mode conditions will be sufficient for ITER. Work is now in progress to provide a more quantitative estimate of helium transport by obtaining the ratio of the local helium diffusion and thermal conductivity D/χ for these discharges.

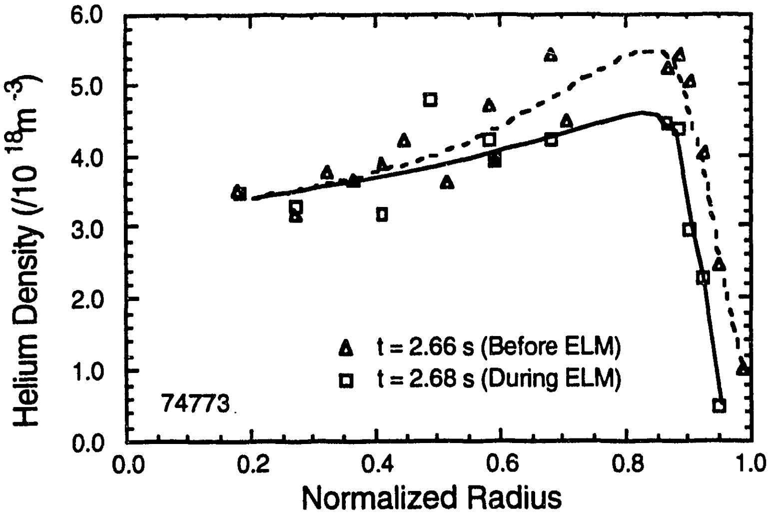

Fig. 3. Helium density profiles measured by just before and after a giant ELM event during a 1.6 MA H–mode discharge.

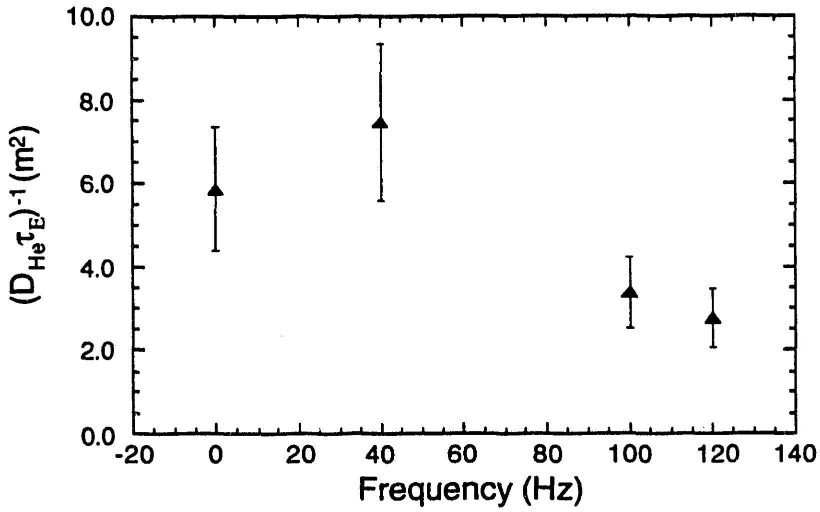

Fig. 4. Scaling of the parameter $1/\left(D_A^{\alpha}\tau_E\right)$ as the ELM frequency is varied from 0 Hz (ELM-free) to 120 Hz.

[1]Hillis, D.L., et al, Phys. Rev. Lett. **65** (1990) 2382.
[2]Synakowski, F., et al., Phys. Rev. Lett. **65** (1990) 2255.
[3]Nakamura, H., et al., Phys. Rev. Lett. **65** (1991) 2658.
[4]Hillis, D.L., et al, J. Nucl. Mater. **196-198** (1992) 35.
[5]Gohil, P., et al., *Fusion Engineering* (Proc. 14th Symp., San Diego 1992) (IEEE, New York), Vol. 2, 1199.
[6]Hulse, R.A., Nucl. Technol./Fusion 3 (1983) 259.
[7]Schissel, D.P., et al., Nucl. Fusion **31** (1991) 73.
[8]Christiansen, J.P., et al., Nucl. Fusion **32** (1992) 291.
[9]Perry, M.E., et al., Nucl. Fusion **31** (1991) 1859.
[10]Luxon, J.L., Plasma Physics & Controlled Fusion (1991).
[11]Thomas, P.R., et al. EPS Conference, Innsbruck, Vol. 16C, Part 1, 239.
[12]Schissel, D.P., et al., EPS Conference, Innsbruck, Vol 16C, Part 1, 235.

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