Progress in Quantifying the Edge Physics of the H–mode Regime in DIII–D* **EX**

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The ELMing H–mode discharge is the baseline scenario for a next-step tokamak device. Predicting the performance of such a machine critically depends on the solution to several challenges for edge physics: 1) understanding the edge conditions required to obtain the H–mode, 2) predicting the H–mode pedestal conditions, which are the boundary conditions for core confinement, and 3) minimizing the divertor heat load due to edge instabilities. H–mode research in the DIII–D tokamak has addressed these three topics in the following ways: 1) the local edge conditions required for the H–mode transition have been examined with studies of pellet-induced H–mode discharges, studies of the ∇B drift effect and evaluation of possible control parameters; 2) pedestal studies have been extended to include the effect of triangularity on the width of the H–mode barrier; 3) an attractive regime of steady-state H–mode operation has been discovered which has no ELMs and thus no pulsed heat load to the divertor.

The possibility that a “critical” edge temperature controls the H-mode transition has been proposed as a threshold criterion for the L-H transition [1]. On DIII-D, at least three lines of research indicate that this is not the case. First, deuterium pellets have induced transitions to H–mode when the heating power was below the nominal H–mode threshold. In these discharges, both the edge T_e and T_i were reduced by approximately 50% in the L–mode by injection of a pellet (see Fig. 1). Nevertheless, the H–mode transition occurred within a few milliseconds after pellet injection. These results are inconsistent with the idea that the H–mode transition occurs when a “critical” edge temperature is achieved.

Second, studies of the ∇B drift effect show that the condition for the H–mode transition depends on more physics than just the edge fluid parameters, density, temperature and

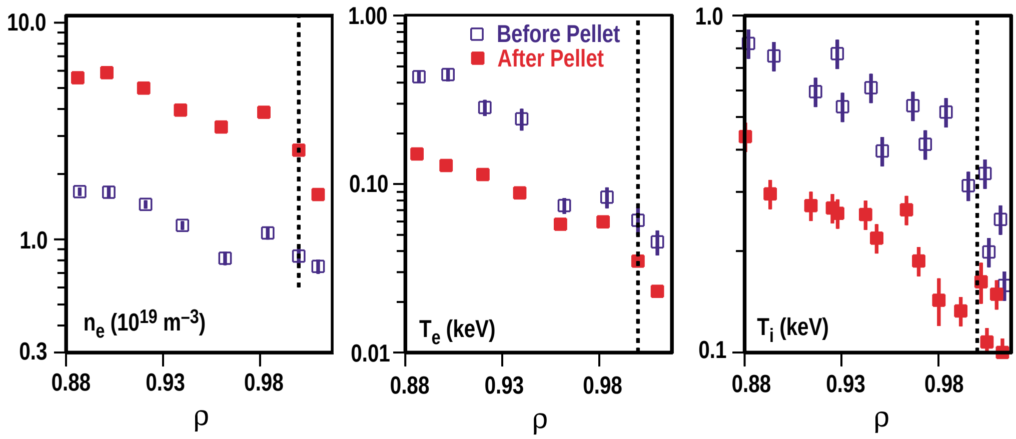

Fig. 1. Edge n_e rises by about factor of 3 and edge T_e and T_i decrease by about 50% from before pellet injection (18 ms before H–mode transition) to after pellet injection (6 ms before H–mode transition). Separatrix shown by vertical dashed lines.

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pressure. In careful experiments, discharges have been prepared with both signs of the toroidal magnetic field B_T for which the edge fluid parameters were nearly identical. However, for one sign of the magnetic field, the heating power was within 10%–30% of the H–mode threshold while for the other sign of B_T, the same amount of power was a factor of 3-5 below the threshold. Thus, the condition for obtaining the H–mode is not just the requirement that a critical value of the edge temperature, pressure or their gradients is achieved. Measurements from both spectroscopy and probes also show that there are changes in the structure of the edge radial electric field E_R in L–mode phase when the direction of B_T is reversed. Both diagnostics indicate that E_R just inside the separatrix becomes more negative when B_T is switched to the direction which gives the higher power threshold. Reversing B_T also causes significant changes in the divertor, such as in recycling characteristics. These changes are evidently caused by a reversal of $E\times B$ flows on the open field lines when B_T is reversed. It is not yet clear if any of these phenomena can explain the ∇B drift effect.

Third, the critical temperature hypothesis is put into doubt by results which show that it is gradients of parameters at the plasma periphery, rather than the fluid parameters themselves, which have a controlling influence on the L-H transition. Studies of possible H–mode control parameters show that gradients of electron and ion temperature and pressure, at the very periphery of the plasma, systematically increase in the L-phase of discharges which make a transition to H–mode. These changes are larger and more consistently observed than changes in the edge temperatures or pressures. For a fixed magnetic configuration, the transition occurs when ∇T_e and ∇P_e reach a fairly well defined threshold. When the magnetic configuration is changed, such as by reversing the sign of B_T, the transition may occur in a different range of ∇T_e and ∇P_e. Clearly, some aspect of the magnetic configuration is important for H–mode threshold conditions, as indicated by studies of the ∇B drift studies. Nevertheless, the systematic increase of these gradients in L–mode suggests that they play a role in the dynamics of the transition, as has been predicted by several theoretical simulations, which have obtained H–mode-like transitions by increasing the pressure gradient [2].

Predicting the core H–mode confinement in future devices requires knowledge of the values of temperature and density at the H-mode pedestal, because these parameters form the boundary conditions for the core plasma. Previous scaling studies in DIII-D have been extended to include the effect of triangularity δ on the width of the pressure barrier Δ_p. In these studies, the height of the H–mode pressure pedestal increased by a factor of two as the triangularity was increased. This increase was due primarily to an increase in the pressure gradient. In contrast, the barrier width Δ_p increased weakly with δ and was found to be consistent with previous studies which show that Δ_p is proportional to $(\beta_p^{ped})^{1/2}$. This scaling remains the best description of barrier ("pedestal") width for a wide range of DIII–D data. A dependence of Δ_p on temperature or ion poloidal gyroradius is inconsistent with experiments which varied the pedestal temperature with gas-puffing and cryo-pumping.

An additional concern for H–mode discharges in a next-step device is that the pulsed heat load due to ELMs will rapidly erode the divertor target plates. An attractive mode of operation has been discovered in DIII–D which does not have this problem. For a range of conditions with counter-injected neutral beams, H–mode discharges exhibit steady-state and ELM-free behavior. These plasmas exhibit density, impurity and radiation levels which are constant through the ELM-free phase. These observations are in marked contrast to the usual H–mode phenomenology in which impurity levels and radiation rapidly increase when ELMs are absent. The ELM-free phase is accompanied by low amplitude coherent MHD modes with n=1–9. It is possible that these modes provide enough transport at the edge to keep the pressure gradient below the level which triggers ELMs and to cleanse the plasma of impurities. These discharges have very desirable characteristics from the point of view of reactor operation. They have standard H–mode level confinement but no pulsed heat load to the divertor.

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