ELMy H-mode Helium plasma at JET-ILW

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Present day tokamaks typically operate with pure deuterium plasmas, as the plasma properties are reasonably similar to those of the D-T fuel mixture sought to be used in a fusion reactor. In future larger devices (ITER, DEMO) even pure deuterium plasma may generate unacceptable neutron fluxes and nuclear activation of machine components. Therefore, for the earlier phases of operation, non-active plasmas are considered - those which generate no fusion power/neutrons at all. While a pure hydrogen plasma is perfectly suitable for the initial commissioning phase, access to H-mode may not be possible in reactor-relevant machines due to the limited auxiliary heating available (as fusion reactors rely on burning plasma self-heating) and the larger L-H transition threshold power P_{LH}~$1/A_{eff}$, [1,2] where A_{eff} is the effective hydrogenic isotope mass. Helium or He+H mixture are considered for the non-active phase of ITER [3] to test the aspects of operating the tokamak in the H-mode regime, and in particular to commission ELM-mitigation techniques, as the L-H threshold for helium plasma was found to be similar to those in deuterium [2].

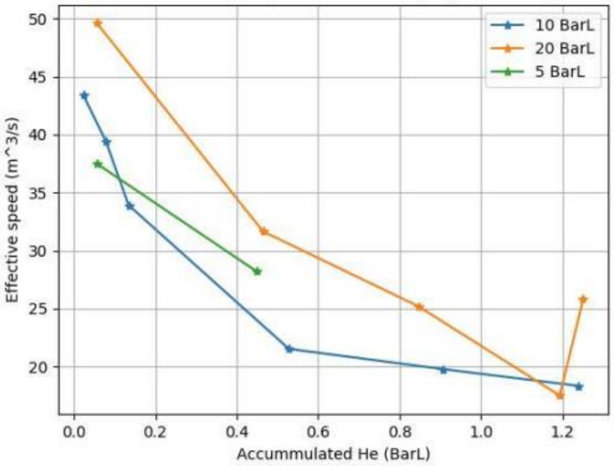

Figure 1: Pumping speed of helium for various Ar-frost amounts, measured with small gas puffs without a plasma.

Experiments with pure helium and He/H mixture have been conducted at JET-ILW to study the H-mode access in non-active plasmas in conditions as close to those of ITER as possible. The JET NBI heating system has been converted to helium injection for that purpose, with a maximum achieved power of P(He-NBI)~13MW. A clean-up and wall conditioning sequence has been performed, which allowed to achieve negligible (<1%) hydrogen/deuterium content in the plasmas for the pure helium part of the experiment. Argon frosting was used on the in-vessel cryopump to improve helium pumping and plasma density control. The helium pumping efficiency was measured prior to the experimental campaign for various thicknesses of the Ar-frost layers and amounts of injected helium gas, the results are shown in Fig. 1. These results are consistent with the previous measurements done in JET-C [4]. 10 Barl of Argon injection prior to every helium plasma pulse was found to be the optimum for the plasmas described in this work, which consumed typically <0.6 Barl of helium in each discharge.

Similar to the methodology described in [2], the L-H power threshold (P_{LH}) has been measured in pure helium, He+H mixtures and pure deuterium reference plasmas. The measurements were done at Bt=1.3T, Ip=1.3MA, in "corner-corner" divertor strike points configuration for the most efficient pumping (options for divertor configuration and its effect on P_{LH} described in [2]). For pure He and He+H mixtures, He-NBI heating was used, while D-NBI was used for the pure deuterium case. Measured P_{LH} for each of the plasma species and various plasma densities are shown on Fig.2. $P_{Martin,08}$ empirical scaling (1) for the L-H power threshold, derived for deuterium plasmas with ion ∇B drift direction downwards to lower divertor [5], is plotted for comparison.

$$P_{Martin,08}=2.15\ n_{e20}^{0.782}\ B_T^{0.772}\ a^{0.975}R^{0.999} \qquad (1)$$

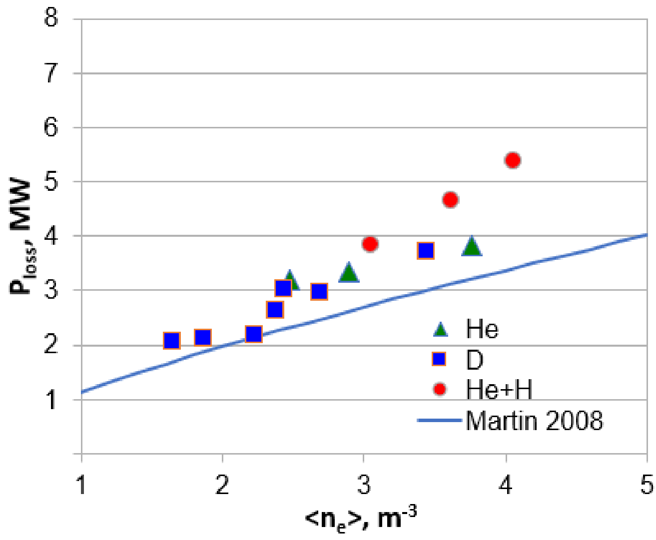

Figure 2: P_{LH} for different plasma species at various line averaged densities, 1.3MA/1.3T, with $P_{Martin,08}$ scaling value for comparison

Similar P_{LH} was measured for helium and deuterium plasmas in the range of line averaged densities $<n_e> \sim 2.5\text{-}3.5 *10^{19}\ m^{-3}$, slightly above the $P_{Martin,08}$ scaling values. This result is consistent with the previous observations made on JET-C for 17MA/1.8T plasmas [6]. A dilution of helium plasma with hydrogen causes the increase in P_{LH}, by around 25% for $n_H/n_e = 0.45$ mixture (see Fig.2)

While the power threshold to access H-mode is a valuable parameter, the tokamak plasmas do not typically show good confinement ($H_{98(y,2)}\sim 1$) when the additional heating power is only slightly elevated above the L-H threshold. To access the higher confinement regime, also called type-I ELMy H-mode (since it is normally characterized by relatively large "type-I" ELMs), typically a higher $P_{aux}\sim 1.3\text{-}1.5*P_{LH}$ is required [5]. Transition to the higher confinement regime (type III -> type I) is usually observed in tokamak plasmas as a sudden change in the ELM behaviour, with ELM frequency quickly decrease to near zero (ELM-free) as the additional heating increases. It is also accompanied by a sudden increase in the pedestal density and overall plasma stored energy.

The ITER Q=10 baseline scenario is thought to be in this confinement regime with the ELMs suppressed by means of the resonant magnetic perturbation (RMP). It is, therefore, highly desirable to achieve a similar confinement regime in a non-active plasma to commission the ELM mitigation in the earlier phases of ITER operation. Unlike P_{LH}, the power threshold for type-I ELMy H-mode access hasn't been systematically studied.

In the previous helium experiments at JET-C [6], P_{III-I} has been measured for helium and deuterium in 1.8T / 1.7MA plasmas. For helium plasmas, P_{III-I} = 7.5-9.3MW has been reported, and similar value P_{III-I} = 6.7-9.3MW was found in the deuterium reference. Relative to the L-H threshold scaling, this corresponds to $P_{III-I}/P_{Marin08}$ = 1.4-1.6 for helium and $P_{III-I}/P_{Marin08}$ = 1.2-1.8 for deuterium respectively. A similar experiment has been performed recently for the JET-ILW at 1.3MA/1.3T, with a power ramp up to 12MW. A clear transition from type III to type-I ELMs was observed with a power step from 8.5MW to 10MW, as shown in Fig.3 in red. At Bt=1.3T and <ne>=0.38*10^{20}m^{-3} in this plasma, the threshold power is therefore found as **P_{III-I}(He)=2.6-3.1*$P_{Martin,08}$.** In H/He mixture plasmas with n_H/n_e~0.5, a transition to type I ELMy H-mode was observed already at P_{aux}=8.5MW, as shown on Fig.3 in blue. At higher power levels of 10MW and 12.5MW (after t=11.8s on Fig.3) the H/He mixture pulse showed steady type I H-mode without back transitions to type III. We therefore conclude that the P_{III-I} type-I access in He/H mixture plasma is at least not higher than in pure helium, despite the difference in P_{LH} shown on Fig. 2

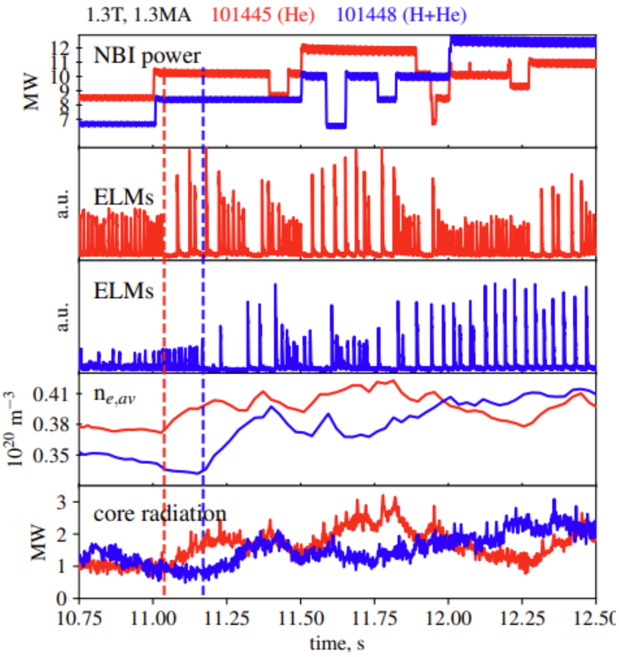

Figure 3: type III-I transition with power ramp in pure He (red) and He/H (blue) mixture plasmas.

Pure deuterium reference pulses were performed at the same values of Bt=1.3T, Ip=1.3MA and identical plasma configuration. In contrast to the results observed in helium plasmas, in the deuterium pulses with line average electron densities $n_{e,av}>0.2*10^{20}m^{-3}$, no type-III H-mode phase was found, as the discharges transitioned directly into type-I H-mode. Possibly, the gap between P_{LH} and P_{III-I} was too small for the JET NBI system to resolve, as the power steps could not be reduced further.

With further increase of the heating power, no sudden change in pedestal behaviour has been observed, with pedestal density monotonically decreasing with the power (Fig 4) and ELM frequency increasing, which is an indication that the deuterium plasma is in type I regime in the whole range of applied heating power. For this particular case, **$P_{III-I}(D)\sim1.0*P_{Martin,08}$**

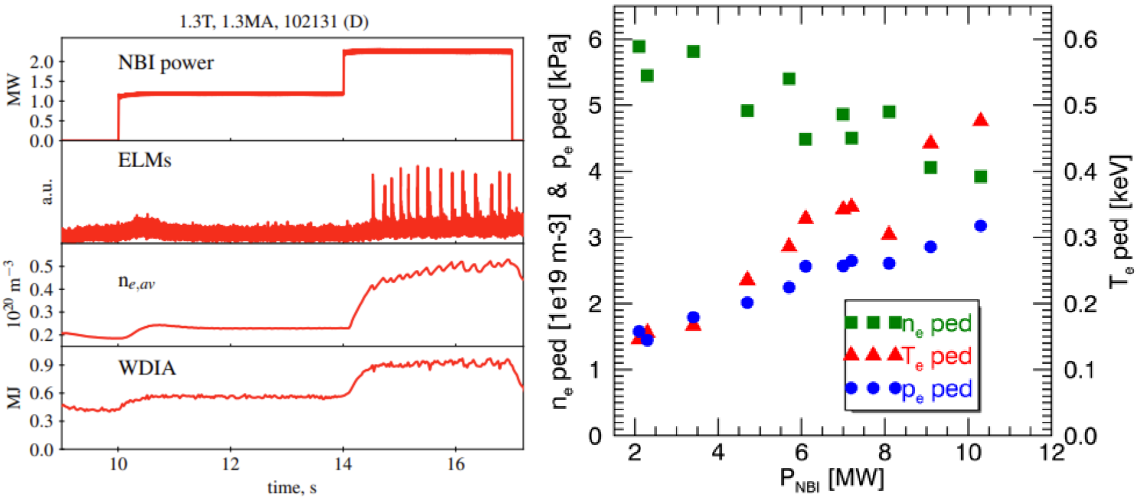

Figure 4: results of P_{III-I} study in pure D plasma, 1.3MA/1.3T. left: L-H transition at P(NBI)= 2.3MW with significant density raise and large ELMs observed, right: H-mode pedestal parameters in these plasmas for different P(NBI), indicating that D plasma remains in type I regime in the whole range of heating power applied.

While the detailed analysis of the helium H-mode plasmas is still underway, two important conclusions can be made from this experiment: 1) the ratio between P_{III-I} and P_{LH} can be significantly different from the 1.3-1.5 range [3,5], and can vary significantly for different plasma species even in the same machine conditions; 2) in JET with ITER-like wall, access to type I ELMy H-mode in helium plasma is significantly more difficult than in deuterium (and possibly similar to the one in hydrogen). The strategy of RMP coils commissioning in helium plasma at ITER as outlined in [3] is therefore carrying significant risk of not being able to achieve the type-I ELMy H-mode conditions.

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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