The effect of helium on plasma performance at ASDEX Upgrade and JET

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Introduction

While it is well known that confinement in helium plasmas is lower than in deuterium plasmas [1, 2], helium is suspected to degrade confinement even when present at low, reactor relevant, concentrations in deuterium plasmas [3, 4]. This degrading effect of helium on plasma performance is demonstrated in dedicated experiments in ASDEX Upgrade (AUG) and JET and is investigated in detail in search of the physics reasons behind the confinement degradation.

Helium seeding in JET baseline scenario plasmas

Helium was added to baseline scenario deuterium plasmas at JET (B_t=2.1T, I_p=2MA, D-fuelling of unseeded pulse $1.6 \cdot 10^{22}$ e/s, $\beta_N \sim 1.5$, $q_{95} \sim 3.1$), in three types of experiments: with neutral beam injection (NBI) heating only, combined neutral beam and H-minority ion cyclotron resonance heating (ICRH), and combined NBI and ICRH with ELM frequency control. The He concentration was scanned up to above 10% from pulse to pulse, controlled in real time using the divertor spectroscopy signals. The He concentration is estimated from divertor spectroscopy measurements (one He level benchmarked also with CXRS measurements, using an approximate correction for the He plume emission contribution).

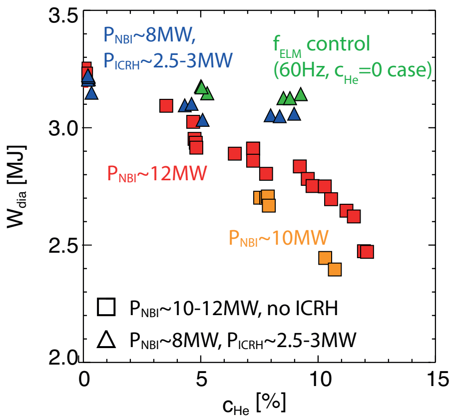

Fig. 1: *Reduction of the plasma diamagnetic stored energy with increasing helium concentration in JET plasmas.*

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+ X. Litaudon et al, Overview of the JET results in support to ITER, accepted for publication in Nuclear Fusion

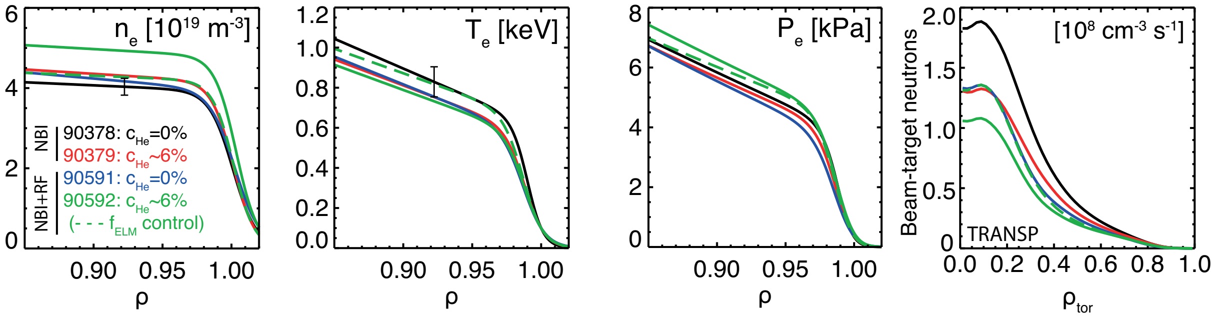

Fig. 2: *Fitted HRTS pedestal profiles of the JET plasmas, with (red and green lines) and without (black and blue lines) He-seeding. The effect of the kinetic profile changes induced by the He-seeding on the beam-target neutron production, simulated with TRANSP, is shown on the right.*

In plasmas with NBI-heating only (P_{NBI}=10-12MW), a strong linear decrease in stored energy (and normalised confinement factor $H_{98(y,2)}$) was observed with increasing He concentration, see Fig. 1 (red and orange points). The plasma stored energy is reduced by ~11% at a He concentration of 5%. A significant reduction of ~30% in measured neutrons is also observed, which cannot be solely attributed to the dilution by He.

The addition of He in plasmas with pure NBI heating leads to an increase of the pedestal electron density and a corresponding decrease of the pedestal electron temperature (Fig. 2, black and red lines). The loss in plasma confinement is not connected to a loss of pedestal pressure, as this remains almost the same with increasing He concentration. The core pressure does decrease, as the peaking of the electron density and temperature profiles reduces. The core ion temperature follows the changes in the electron temperature. Pedestal ion temperature measurements were not available for these shots. However, consistency checks have shown that the pedestal ion temperature follows the behaviour of the pedestal electron temperature. In the pulses with He seeding, two bands of ELM frequencies appear, for example, 35 and 80Hz with the first level of He, while only the lower ELM frequency is present in the unseeded case.

When part of the NBI power is replaced with central H-minority ICRH heating (P_{NBI}=8MW, P_{ICRH}=2.5-3MW), the electron temperature as well as the total neutron rates are not as strongly reduced (Fig. 2, blue and green solid lines). The pedestal electron density increases more strongly with the addition of He in comparison to the NBI-only heated case. The pedestal electron density could be kept at the levels of the unseeded pulse (Fig. 2, green dashed lines), when the ELM frequency was controlled in real time to the frequency of the non He-seeded pulse (~60Hz, with ICRH and NBI heating), by reducing the D gas puff.

The higher edge density induced by He in the NBI-only plasmas leads to a stronger attenuation of the NBI in the plasma and reduced central heating, which in combination with the reduced core temperature leads to a significant reduction of beam-target neutrons (TRANSP simulation shown on the right of Fig. 2, thermal DD neutron contribution is <15% of the total neutrons). With the addition of ICRH, the degrading effect of He on the plasma performance is limited. The temperature is kept high, which, in combination with increased electron density, increases the pressure in comparison to the unseeded case. With the reduction of the D-fuelling, the NBI attenuation was no longer affected and the confinement of the plasma without He-seeding was recovered. The D gas, however, was reduced much more than the added He gas.

Helium seeding in ASDEX Upgrade high confinement plasmas

Helium was added with 0.5s long gas puffs to high confinement AUG deuterium plasmas, (P_{NBI}=10MW, P_{ECRH}=1.3MW, B_t=2.5T, I_p=1MA, $\beta_N \sim 1.9-2.3$, $q_{95} \sim 4.3$) with two different levels of D fuelling ($5 \cdot 10^{21}$ and $7.5 \cdot 10^{21}$ e/s), as well as to N-seeded deuterium plasmas, leading to He concentrations of up to ~14%. The He density profile is measured with CXRS, taking into account the plume effect [5]. A clear reduction of the plasma stored energy, shown in Fig. 3, as well as a clear effect on the pedestal and core profiles were observed when He was puffed.

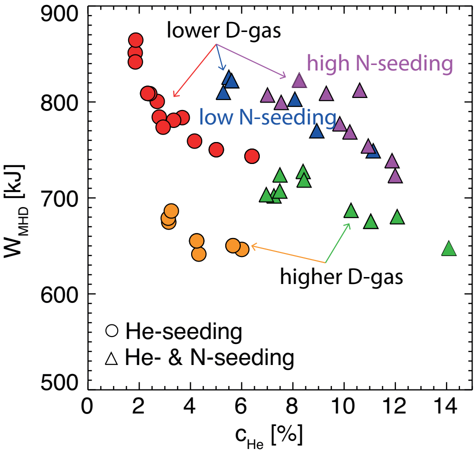

Fig. 3: *Plasma stored energy versus He concentration in AUG plasmas.*

Both with and without N-seeding, the He-puff leads to no or small increase of the electron density pedestal and a reduction of the electron and ion temperatures. These changes are stronger at lower D-gas fuelling. Fitted pedestal profiles for such a discharge are shown in Fig. 4 (profiles before the He-puff in blue and immediately after in green). Dilution due to He (and N) cannot by itself explain the observed reduction in stored energy. Rather, the reduction in plasma stored energy is mainly due to the changes to the kinetic profiles induced by the He puff. In contrast to JET, the pedestal pressure is slightly reduced, with the effect being larger for the ions. The peaking of the kinetic profiles in the confinement region does not change significantly with the He-puff and as a result the core electron density increases up to a maximum of 5%, while the ion temperature is reduced more strongly than the electron temperature with the addition of He. These observations agree with those reported in [3], where an erosion of the ion pedestal was also observed.

In the plasmas with the higher level of D-fuelling and in the absence of N-seeding, two distinct ELM frequencies are present and a high field side high density front is observed in the SOL (HFSHD [6]). The He puff affects neither the ELMs nor the HFSHD. In the low D-fuelling cases, without N-seeding, two ELM frequencies are also observed, and the upper ELM frequency band is populated more with the He-puff. With N-seeding, the HFSHD is reduced, leading to an increase of the plasma stored energy and confinement improvement [7, 8]. When

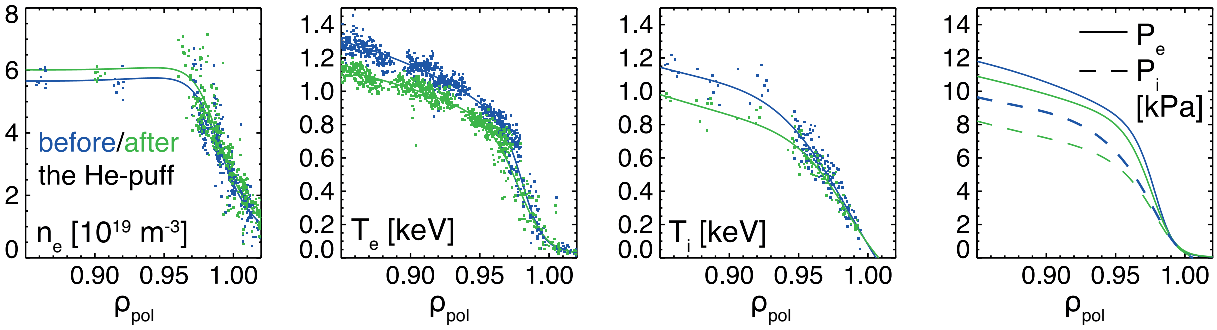

Fig. 4: *Pedestal profiles for AUG discharge 34176 (low D-fuelling), before (blue, at 2.7s) and immediately after (green, at 3.5s) the He puff injected during 3.0-3.5s.*

He is added, the HFSHD reappears and the ELM frequency increases, accompanied by a reduction of the N concentration across the plasma radius. The reason for this interplay between the two impurities needs to be investigated further.

Discussion and conclusions

The degrading effect of He on plasma performance has been demonstrated at JET and AUG. Despite the fact that the two experiments are not directly comparable (different approaches to the He puffing, lower power flux in the JET case), the effect of the He-seeding on the kinetic profiles has a phenomenological similarity: an increase in the electron density, accompanied by a reduction of the electron and ion temperatures. However, in AUG, a constant pedestal pressure is not sustained and the reduction of the produced neutrons is stronger in the JET plasmas. With the use of ICRH heating and a reduction of the D gas, it was possible to minimise the effect of He on the confinement at JET. In both experiments, the stored energy recovers after a He gas puff on the same time scale as the He concentration decays, which is defined by wall recycling and pumping and is different for the two experiments.

Compared to future fusion reactors, where He will be produced in the core, He can only be added as an extrinsic impurity in present day experiments. Thus, not only transport effects, but also He pumping and recycling mechanisms, which will determine the He density [9], have to be understood in order to make valid predictions for future reactors.

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