Improved plasma performance via low-Z powder injection in the Large Helical Device

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We report the results from recent impurity powder injection experiments in the Large Helical Device in Japan, conducted over the last three years (2019-2022). With the main goal of improving wall conditions and plasma performances, different low-Z materials (B, BN, B_4C, C, Li) sub-millimeter powders have been injected into the plasma under the action of gravity using the Impurity Powder Dropper (IPD) [1]. The installation of the IPD was guided by EMC3-EIRENE and DUSTT simulations [2] to optimize the powder penetration in the LHD unique magnetic geometry.

One of the main results of this series of experiments is the improvement of wall conditions: reduction of intrinsic impurity content C, O, Fe and reduction of wall recycling, both on a shot-to-shot basis and in real time [3].

Leveraging these results by injecting boron powder in minute-long discharges, an otherwise occurring radiative collapse was successfully avoided [4].

Furthermore, the access to a reduced-turbulence improved confinement regime was observed upon boron powder injection [5] at constant power and line averaged density, resulting in an increase of the plasma temperature on the order of 25%, but with an increase of ion temperature that can be as high as 50%. At the same time, the turbulent fluctuations amplitude has been measured to decrease by up to a factor of 2.

Access to this regime has been investigated in extensive dedicated experiments [6], and has been observed for different powder materials, heating schemes, plasma main ion species (H and D), and for both directions of the magnetic field.

The main mechanism behind this improvement of confinement is not fully understood yet, but is most probably due to the suppression of ITG turbulence driven by plasma profile modification and increase of effective charge resulting from the impurity powder injection.

Leveraging the increase of confinement during powder injection, B powder has been injected into the high ion temperature scenarios (low density and high power plus C pellet injection), resulting in a further increase of T_i of about 50% [7].

Simulation efforts to better understand dynamics of powder injection into the LHD plasma and help optimize real time wall conditioning and the access to the improved confinement regime are ongoing [8].

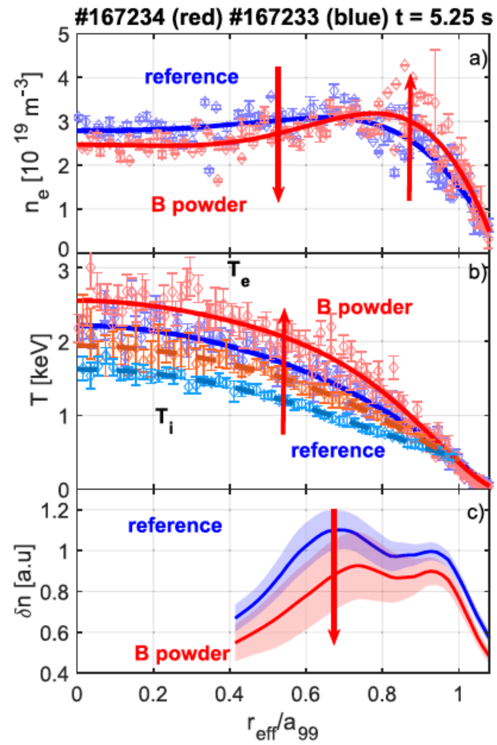

Figure 1: Radial profiles of (a) electron density (b) electron (solid lines) and ion temperature (dashed lines) (c) turbulent fluctuation amplitude measured by PCI, for a boron injection discharge (#167234, red) and its reference (#167233, blue), at t=5.25 s (during injection). Reprinted from ref. [6].

References

[1] A. Nagy et al., Rev. Sci. Instrum. 89 10K121 (2018)
[2] M. Shoji et al., Contrib. Plasma Phys. 60 e201900101 (2019)
[3] R. Lunsford et al., Nucl. Fusion 62 086021 (2022)
[4] S. Masuzaki et al., this conference
[5] F. Nespoli et al., Nat.Phys. 18 350–6 (2022)
[6] F. Nespoli et al., Nucl. Fusion 63 076001 (2023)
[7] H. Takahashi et al., in preparation
[8] M. Shoji et al., this conference