H-Mode Pedestal Studies with Seeding and Fuelling on TCV

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Introduction

The edge pedestal of a tokamak operating in high confinement mode (H-mode) is a narrow region of reduced turbulent transport at the edge of the plasma. The fusion power produced is strongly dependent on pedestal properties and therefore an understanding the physics of pedestal dynamics remains a critical subject for magnetic confinement fusion [1]. To this end, research has been performed to understand, control and predict the pedestal structure [2, 3]. On metal wall machines such as JET-ILW and AUG, it was found that fuelling has limited or detrimental effect. Nitrogen seeding, however, has shown improved confinement in the pedestal region [6]. Previous studies on AUG and JET with carbon walls showed a degredation in confinement with fuelling and no improvement with nitrogen seeding [4, 5]. The goal of this work was to study energy confinement in nitrogen seeded and fuelled plasmas on the carbon wall device TCV.

Experiment Design

The plasma scenario for these experiments had a triangularity of 0.4, elongation of 1.6, line averaged electron density of 6.5e19 m^{-3}, plasma current of 210 kA, q_{edge} of 6 and additional neutral beam heating of ~1.0 MW together with varying levels of deuterium and nitrogen injection. Two constant levels of fuelling and seeding were utilised per shot. The flow rates and shot numbers are defined in Table 1. The high gas flow rates were set to be below the detachment threshold, as confirmed by Langmuir probes and divertor spectroscopy.

Table 1: Gas flow rates for the seeding and fuelling experiments.

Injection Gas	Low Flow Rate	Shot #	High Flow Rate	Shot #
Nil (Reference)	Valve Closed	53763		
Deuterium (Fuelling)	4.1e20 particles/s	53709	8.1e20 particles/s	53766
Nitrogen (Seeding)	1.7e20 particles/s	53706	4.0e20 particles/s	53707

Results

The TS system measures electron density (n_e) and electron temperature (T_e) with a maximum temporal resolution of 60 Hz at 47 measurement locations. The reference scenario overlayed with TS locations is shown in Figure 1. Multiple pre-ELM measurements were combined and fitted to a mtanh function to parameterise the pedestal profiles presented in this paper. This technique resulted in small differences in the time between each datapoint and the next ELM but by comparing individual profiles, it was observed that this time difference did not effect the conclusions.

Deuterium Fuelling Results

The fuelled pedestal profiles, presented in Figure 2, show an increase in pedestal top n_e with a small decrease in T_e as the gas injection level increases. The consequent changes in pedestal top electron pressure (P_e) relative to the reference case were smaller than the TS uncertainty. Outliers are apparent at poloidal flux radius (ρ) of 0.82. This is due to an error in calibration of spectrometer 10 and the datapoints are presented to show any relative change.

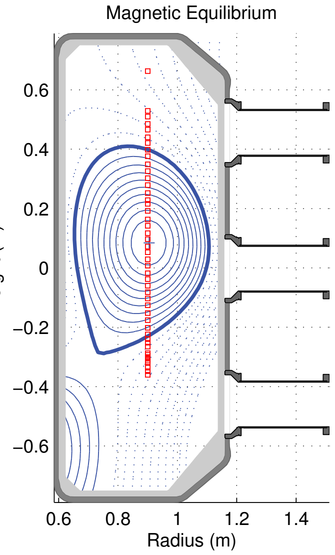

Figure 1: TS measurement points and reference shot plasma equilibrium.

The complete plasma TS profiles, presented in Figure 3, show an increase in n_e for increased fuelling. For low fuelling, core T_e increased whereas the high fuelling level decreased core T_e. Core P_e increased by 12-13% for low fuelling and 2% for high fuelling. No significant changes were observed on the diamagnetic loop (DML) energy measurements and no trend observed in the ion temperature (T_i) measurement from the Charge eXchange Recombination Spectroscopy (CXRS) to suggest a change in electron-ion energy exchange. An explanation for the increase has yet to be identified. The integrated P_e was highest for the high fuelling case due to the increase in pressure profile between ρ of 0.3 to 0.7. This increase was ascribed to the stabilisation of a 12 kHz mode with the additional fuelling.

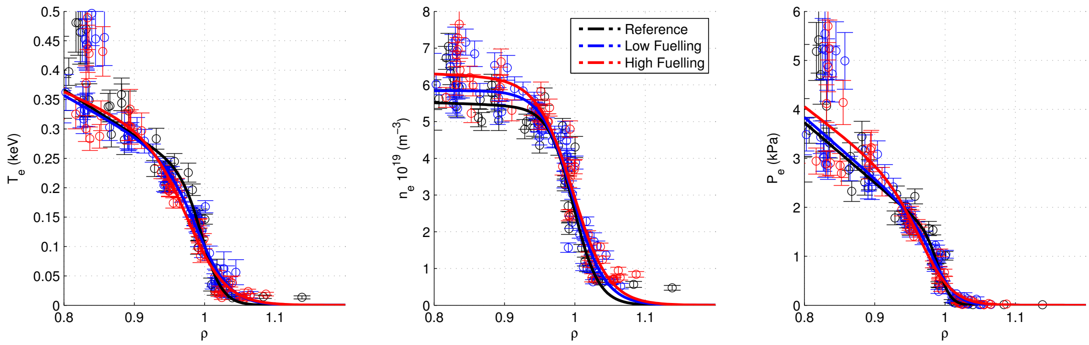

Figure 2: TS pedestal profiles for the fuelling experiments.

Nitrogen Seeding Results

Contrary to the fuelling results, the pedestal top n_e decreased with additional seeding as shown in Figure 4. Both seeding levels had a higher pedestal top T_e than the reference case with a resulting negligible change in P_e. Once again, the outliers at ρ= 0.82 due to the calibration of spectrometer 10 are apparent. Core n_e, presented in Figure 5, was comparable between the

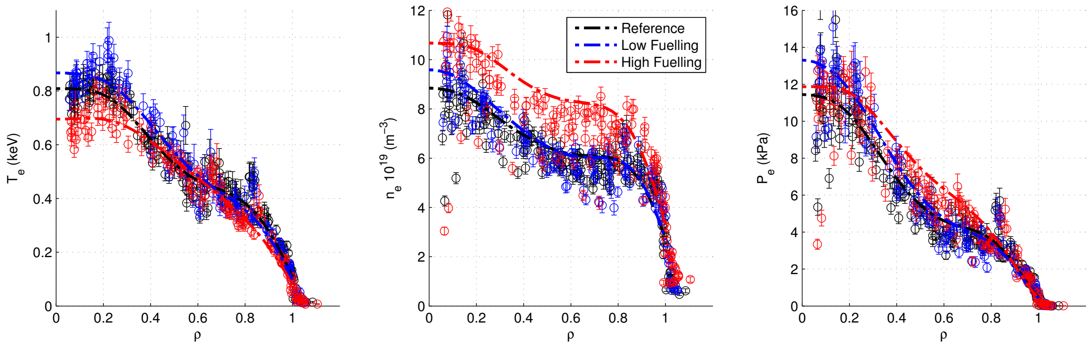

Figure 3: Full plasma TS profiles for the fuelling experiments.

reference and high seeding case, but an increase of approximately 10% was observed with low seeding. Core T_e and P_e increased significantly for both seeding levels. Increases in integrated P_e were measured for the low and high seeding levels.

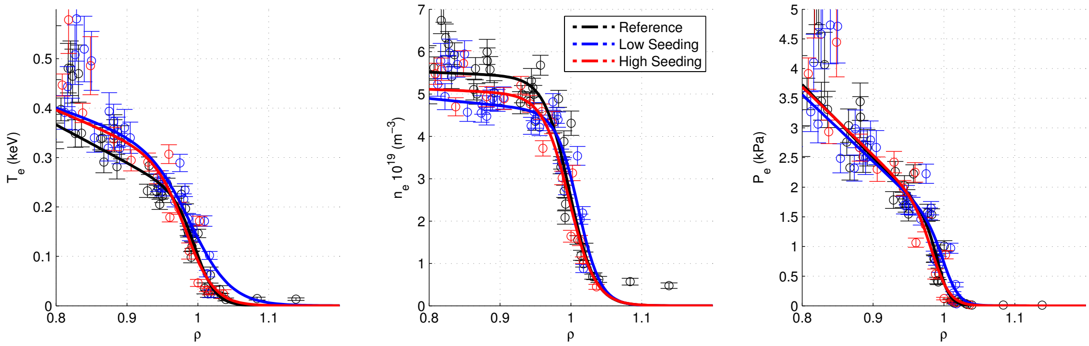

Figure 4: TS pedestal profiles for the nitrogen seeding experiments.

No mechanism has been identified to explain the increases in integrated P_e observed. Figure 6 shows the ohmic input power, total stored energy and radiated power for each case. 1.0 MW of NBH was applied between 0.8 and 1.3 s for each shot. With increasing seeding gas level, an increase in radiated power was expected and observed. In contrast to the TS measurements, the low seeding case showed no increase in ohmic power with increasing Z-effective and no increase was measured by the DML. Finally, T_i from CXRS showed no apparent trend with increasing gas level that might have resulted from a change in the electron-ion energy equipartition.

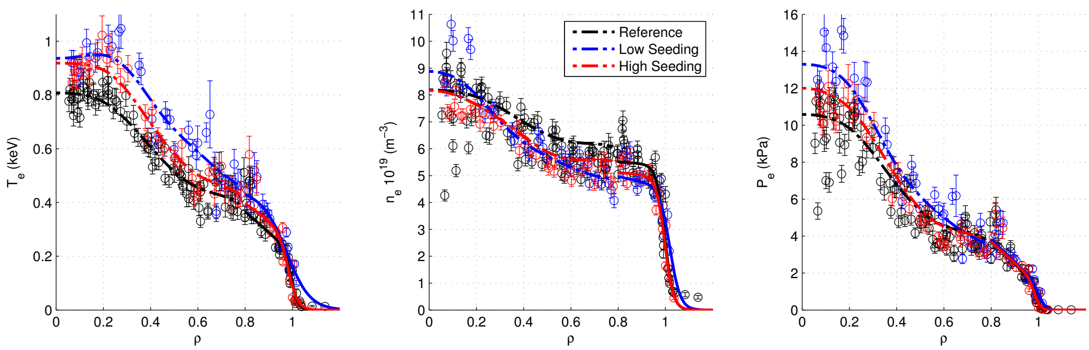

Figure 5: TS profiles for the nitrogen seeding experiments.

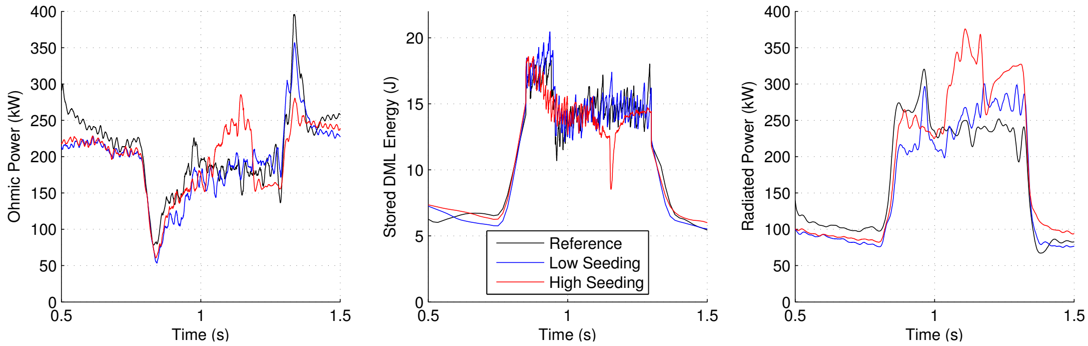

Figure 6: Input ohmic power (left), stored DML energy (centre) and radiated power (right) for the nitrogen seeding experiments.

An increase in ohmic power was observed for the high seeding case from 1.1 s that led to a large increase in radiated power, followed by a sharp drop in DML stored energy before a sawtooth crash expelled the impurity build up and allowing the plasma to recover at 1.25 s. Consequently, The TS profiles were only used until 1.1 s for this shot. An increase in P_e was measured during this time but once again no changes in DML stored energy, or a clear decrease in ion temperature, were observed.

Conclusions

Experiments were conducted on the TCV tokamak to study the effect of energy confinement with nitrogen seeding and additional fuelling. No major changes on the pedestal top P_e with gas injection were seen. The nitrogen seeding results are in agreement with experiments carried out on other carbon wall machines and no degredation of the pedestal top was observed with additional fuelling. Significant increases in core P_e and integrated P_e were observed for the fuelling and seeding experiments. Simulations and further analysis are ongoing to identify possible causes.

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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