

Recent Results of LHCD Coupling Experiments with Near Gas Injection in JET

G. Granucci¹, A. Ekedahl², J. Mailloux³, K. Ereñts³, M. Hron⁴, E. Joffrin², P.J. Lomas³,
M. Mantsinen⁵, J.-M. Noterdaeme^{6,10}, V. Pericoli-Ridolfini⁷, V. Petrzilka⁴, K.
Rantamäki⁸, R. Sartori⁶, C. Silva⁹, A.A. Tuccillo⁴, D. McDonald³
and JET EFDA contributors

¹Associazione EURATOM-ENEA sulla Fusione, IFP-CNR, Milan, Italy

²Association EURATOM-CEA, CEA-Cadarache, France

³EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, UK

⁴Association Euratom-IPP.CR, Praha, Czech Republic

⁵Helsinki Univ. of Technology, Association Euratom-Tekes, HUT, Finland

⁶Max-Planck-Institut für Plasmaphysik, Euratom Association, Garching, Germany

⁷Associazione EURATOM-ENEA sulla Fusione, CR Frascati, Rome, Italy

⁸Association Euratom-Tekes, VTT Processes, Finland

⁹Associação Euratom-IST, Centro de Fusão Nuclear, 1049-001 Lisboa, Portugal

¹⁰Gent University, EESA Department, Belgium

Introduction

Dedicated gas injection in the proximity of the Lower Hybrid Current Drive (LHCD) launcher is used routinely in JET for obtaining a good and stable coupling of the LH waves in severe conditions: H-modes, ITB (Internal Transport Barrier) plasmas and presence of strong Edge Localized Modes (ELMs). Moreover this technique is one of the candidates for allowing the coupling of LHCD power in ITER, where the distance between the Last Closed Flux Surface (LCFS) and the wall is expected to be more than 12 cm.

The dedicated gas pipe (GIM6) was installed in JET in 1995, at a distance of 1.2 m from the LH launcher, in the equatorial plane. It has been used in the past to inject deuterium with different results [1,2], but has become an essential tool for LH coupling in high power phase of advanced scenario plasmas, injecting CD₄ [3]. The CD₄ was introduced for its larger ionization cross-section (σ) and lower ionization potential (12.5 eV against the 13.9 eV of D₂). This can lead to the proper densification of the SOL plasma with lower gas flow with less influence on the quality of confinement. Nevertheless the analysis of the results obtained with CD₄ [4] evidenced that the simple local ionization of the gas alone cannot explain the amplitude of the effects (the increase of the SOL density) and some mechanism of modification of transport in the plasma edge has to be involved.

Aiming at demonstrating the possibility of using LHCD in ITER conditions (large clearance between LCFS and LH grill) and to assess the role of σ in the control of the

SOL density, an experiment with different gasses from the same injecting pipe was carried out on JET.

Experimental setup

The experiment was carried out in spring 2003 in two different experimental sessions. In the first we used CD_4 and D_2 while in the second one, on the same plasma configuration, propane (C_3H_8), ethane (C_2H_6) and D_2 were injected from GIM6. Standard propane and ethane were chosen both for the greater ionization cross section [5,6], with respect to CD_4 and D_2 (see fig.1), and for the easiness of procurement, with respect to the deuterated versions, that have no significant differences in cross section and ionization potential. Despite the fact that hydrocarbides will not be used in ITER, because of their tritium retention, the σ related results will be relevant in general. The plasma target was chosen to be reactor relevant: H-mode with ITB, type I ELMs and large distance between the LCFS and the launcher (8 – 11 cm), with the timing of the additional power as used in experiments aimed at achieving long pulses with steady state ITBs [7]. This scenario, with $I_p=1.5\text{MA}$ and $B_T=3\text{T}$, relies on a fast current ramp-up with 2-2.5MW LHCD, in order to produce a target q-profile with negative magnetic shear, before the application of Neutral Beam Injection (NBI) and Ion Cyclotron Resonance Frequency (ICRF) waves. High NBI power (14 – 15 MW) was requested in these experiments in order to produce type I ELMs. The ICRF power was maintained at a moderate level, and the ICRF antenna located immediately next to the LH launcher was deselected for its detrimental effects on LH coupling. The launcher position was typically at 1 cm behind the poloidal limiter, but it was also varied between 2.0 and 0.5 cm. In all the pulses the density profiles in the SOL was obtained by a Reciprocating Probe (RCP), magnetically connected with the LH grill and the injecting gas pipe (GIM6). The ICRF power was reduced during the RCP swept, in order to avoid the disturbance of the probe measurement.

LHCD coupling and main plasma behaviour

For all the tested gasses a good LH wave coupling was obtained, but different gas flows were required. With CD_4 a good coupling was obtained with a rate of $1 \cdot 10^{22}$ el/s at distance of 7 cm between LCMS and the limiter. Increasing the clearance by 1 cm the rate has to be increased up to $1.2 \cdot 10^{22}$ el/s, indicating that this is the working limit for CD_4 . Injecting D_2 , a good coupling was obtained up to 10 cm with a flux of $0.6 \cdot 10^{22}$ el/s while we found poorer coupling at lower flux ($0.35 \cdot 10^{22}$ el/s). Propane and ethane were tested at smaller distance (7 cm) with a rate of $0.4 \cdot 10^{22}$ el/s and $0.3 \cdot 10^{22}$ el/s respectively. Good

coupling was obtained in both cases and, for the reduced number of pulses available, no limits in rate were found. The data shown refers only to the H-mode phase of the pulse, all of which had similar auxiliary heating power. A clear influence on ELMs (frequency increase and amplitude reduction) was observed for D_2 , C_2H_6 and C_3H_8 , while no change was observed with CD_4 , at least at the used fluxes. The reduction in ELMs, in case of D_2 injection, leads also to an increase of ICRH coupling efficiency. The ELMs amplitude reduction coincides with gas injection and it is not related to the presence of LHCD power.

Regarding the effects on the main plasma, the injection of different gasses does not affect the confinement (H factor = 1.4 for the selected pulses), or the ITB quality. The neutron yield reaches at least $5 \cdot 10^{15} \text{ s}^{-1}$ for all the considered pulses.

Scrape-off layer measurements

In fig. 2 the SOL density profile as measured by the RCP is shown. The presented data is collected from different pulses with different gas rate. Normalizing all the data at the same gas rate the spread is clearly reduced (see fig. 3). The density obtained with the injection of hydro-carbides scales with the ionization-cross section, while D_2 produces an unexplained greater density. A possible mechanism to explain such behaviour could be related to the recycling, which is more affected by D_2 than by the other gasses.

The electron temperature profile is flat in the SOL, and temperature goes from 25 to 35 eV for all the measured cases (D_2 , C_2H_6 and C_3H_8). No clear variations are observed using different gas rates. Comparing the SOL electron density profile with or without LHCD power, we observe an increase during the injection of the LH wave, at least in the case of D_2 injection (see fig.4). The increase is more pronounced in the outer region of the SOL, indicating a possible direct effect of the LH wave on the ionization rate accompanying the recycling effect mentioned above. At the moment no data for comparison with the other gasses is available.

References

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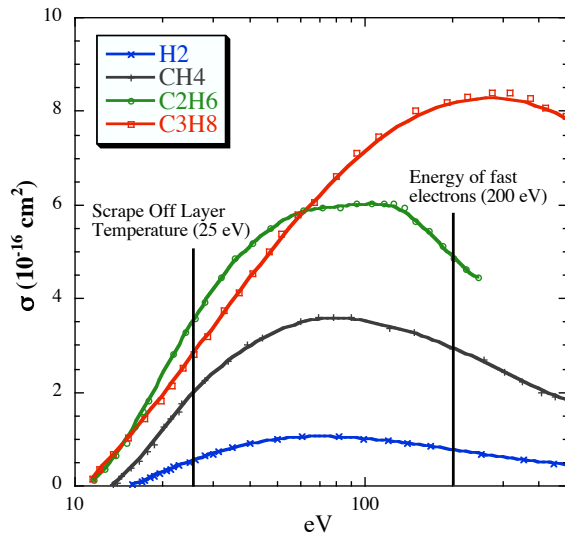


Fig.1 Total ionization cross-section vs impact electron energy. The data are taken from ref [5,6]. No modifications have to be considered in case of deuteration of the gasses.

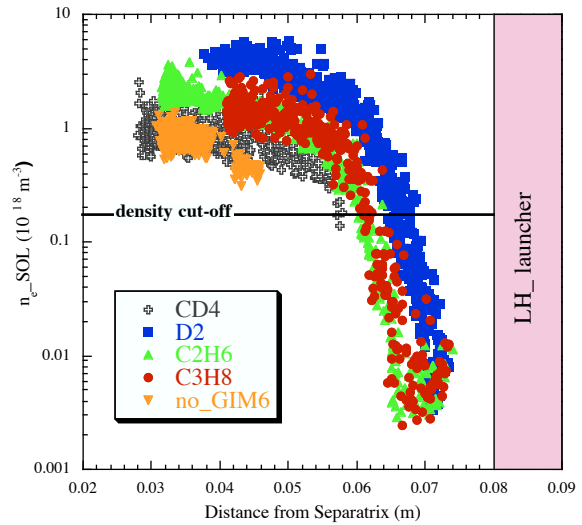


Fig. 2 Density profile in the SOL as measured by RCP. The data are projected on the equatorial plane. The density cut-off for the LH wave in JET is reported.

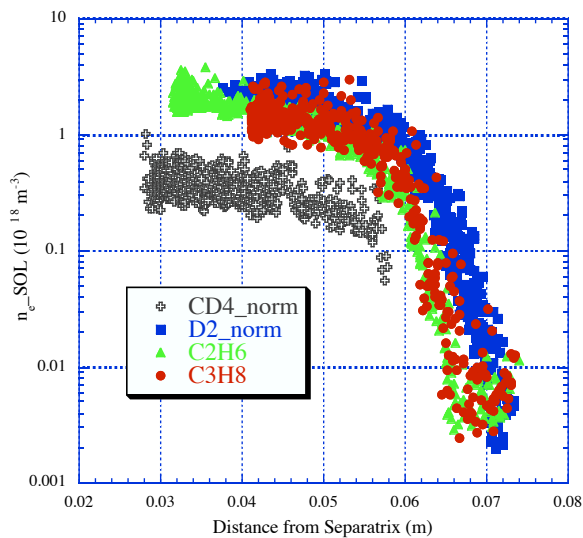


Fig.3 Density profile in the SOL as measured by RCP. The data, for CD₄ and D₂, are linearly normalized at the same electron rate of propane and ethane cases ($4 \cdot 10^{21}$ el/s).

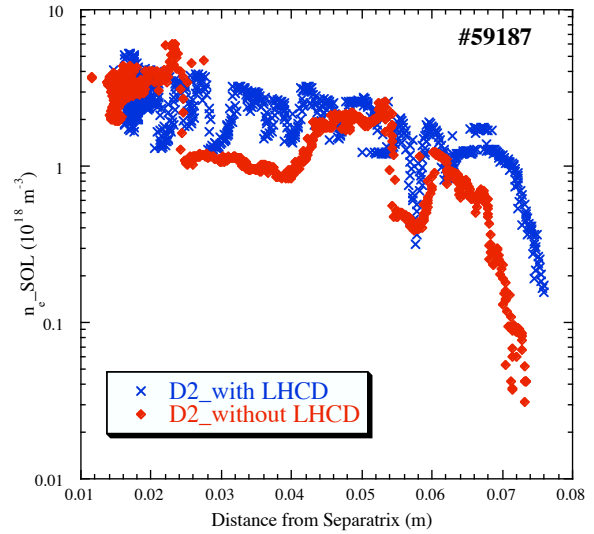


Fig.4 Electron density profile in Scrape Off Layer with or without the injection of LHCD wave. Deuterium is injected from GIM6 at the rate of $5 \cdot 10^{21}$ el/s.