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Li dust injection experiments into T-10 tokamak

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HIGHLIGHTS

- A 0D model developed to study T-10 plasmas during Li dust injection.
- The deuterium recycling coefficient drops from 0.92 to 0.80 during Li injection.
- The effective charge grows during the injection from 2.3 to 3.6.
- Li dust injection provides the best recycling conditions at the lowest Li consumption.

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ABSTRACT

An improved 0D transport model has been applied to model the deuterium, lithium and carbon densities of T-10 plasmas during Li dust injection. The deuterium recycling coefficient is found to drop from 0.92 to 0.80 during Li dust injection at the expense of higher Z_{eff} values. The dust injection results are compared with the alternative techniques, Li pellet injection and Li evaporation. Dust injection provides the best recycling conditions at the lowest levels of Li consumption.

1. Introduction

The technology of lithium injection can be used for different applications: for better density control by decreasing the working gas recycling coefficient, for wall conditioning by the reduction of high-Z impurity fluxes from plasma facing components (PFC), for the reduction of heat loads onto divertor plates by means of non-coronal Li radiation at the plasma periphery (see [1] and references in it) and ultimately to improve plasma performance by processes not yet identified in all detail. Both limiter and divertor plasmas benefit from the use of Li injection. In all cases, wall recycling decreases. However, the mechanisms could be different because the recycling is different in these two concepts. With limiter, the dominant recycling is localized and happens close at the plasma surface; the limiter also represents the dominant impurity source, whereas the main impurity can change from the limiter material to lithium. Therefore, specifically in limiter plasmas the trade-off between reduction in recycling and increase of Z_{eff} has to be considered.

We have tested lithium injection into T-10 tokamak plasmas. T-10 is a limiter device of medium size with a combined poloidal ring limiter and a movable rail limiter whose toroidal position is indicated in Fig. 1. The plasma cross-section is defined by the rail limiter which protruded by 9 cm from the ring limiter. The motivation of the Li-injection technique into T-10 results from the observation of carbon being the major impurity originating predominantly from the graphite limiter elements and from the lack of strict density control for many discharge scenarios indicative of a recycling coefficient above one for these cases.

In order to identify the best injection method, several techniques have been tested. In this paper we report on the results of a new technology of Li dust injection during the discharge. The studies presented here complement those where Li pellets were injected and where Li was evaporated prior to the discharges. The new technology should finally lead to a process where Li-injection can be used during steady-state plasma operation with the benefit of better reproducible conditions as Li is introduced into each discharge in order to prepare a target plasma with constant parameters. The results with pellet injection have been published in Ref. [2]; those

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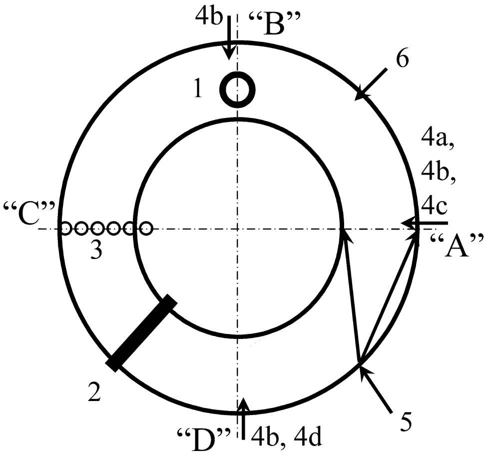

Fig. 1. The experimental setup on T-10 tokamak: 1 – Li injector; 2 – ECE diagnostics of electron temperature; 3 – microwave interferometer for density measurements; 4 – a set of line-integrated spectroscopy signals: CIII (4a), LiII (4b), D_β (4c), continuum (4d); 5 – video camera equipped with an LiII filter; 6 – position of the deuterium gas puff valve. Rail and ring limiters are in cross-section "A".

on Li gettering in Refs. [3,4]. Details of the dust injection technique and initial results were published in Refs. [5,6]. In this paper we will try to identify the benefits of Li-dust injection by comparing the major parameters with relevance to modified wall conditions – the recycling coefficient R_D and Z_{eff}. The analysis is done on the basis of a simple 0D model. The capability of Li dust injection is compared with the one of Li pellet injection and Li gettering.

2. Experimental layout

The lithium dust injector based on the rotary feeder technique has been developed and installed at T-10 tokamak [5] via a set of funnels for adjusting the injection to the port axis and for mechanical decoupling of the injector from the T-10 vacuum vessel. The structure of the injector is as follows: the dust hopper filled with industrially produced metal lithium dust (SMLP$^{\mathrm{TM}}$ – metal Li spheres with averaged diameter ~45 μm covered by ~50 nm layer of Li_2CO_3) is placed inside the vacuum chamber. When the rotation from the step motor is transmitted by the feed through to the hopper, the dust particles are leaving it through the pipe and fall vertically down into the plasma. Injection durations from 100 to 1000 ms have been tested. 500 ms duration time of the dust injection was chosen as it matches the plateau phase of the T-10 plasma current. Test bed measurements yielded flow values of $(1–10) \times 10^{21}$ at/s at the injector outlet with 50 ms transient times. The flow can be changed by both the inclination angle between the injector plates and the rotation rate. The funnel system changes, however, the temporal behavior of the dust jet at the feeder outlet.

The flow from the funnel version had an order of magnitude lower rate and larger (200–250 ms) transit times. This problem caused difficulties of an independent evaluation of the Li dust flow reaching the plasma.

The dust velocity after leaving the injector is determined by gravity. A dust grains velocity of about 4 m/s on its way from the last funnel to the plasma was evaluated.

The present experimental set-up of the lithium dust experiments on T-10 tokamak is shown in Fig. 1 (view from above). The injector is situated in the toroidal cross-section "B", while both limiters (main sink of Li) are in the toroidal cross-section "A" together with spectroscopic diagnostics. The main plasma parameters of ohmically heated plasmas were: major radius: 150 cm, minor radius: 30 cm, line-averaged density: about 2×10^{13} cm^{-3}, central electron temperature: 1.1 keV, plasma current: 200 kA, toroidal magnetic field: 2.5 T. These conditions were selected because they represent a typical ohmic plasma discharge in T-10.

The Li flow rate into the plasma can be estimated using the plasma response onto the injection. They are found to be more than an order of magnitude smaller than the one measured at the feeder outlet. In the paper we are referring to the quantity of Li that actually reached the plasma. The possible reasons of this significant flow reduction could be: (1) dust is captured on the funnel surfaces and then falls from them into the vacuum vessel due to vibrations during the major disruption of the plasma shutdown scenario; (2) dust with small velocity charges up in the shadow of the limiter region before it reaches the LCFS and then distributed along the magnetic field lines over the torus vessel as it is expected for dust in tokamaks. Li dust has been found in the bottom port in the toroidal cross-section where it was injected from the top (cross-section "B"). As a consequence the Li injection setup with excluding the funnels is foreseen.

3. Experimental results

The temporal behavior of plasma parameters at a moderate Li injection rate into a plasma of about 1×10^{20} at/s in shot #61648 is shown in Fig. 2 in magenta. Black curves are obtained from a reference shot #61645 without Li dust injection. The dust reached the plasma after 600 ms as indicated by the start of LiII emission (Fig. 2b). The plasma density was growing slightly during the injection (Fig. 2a) causing a decrease of the gas puff rate (Fig. 2d) regulated by a feedback system programmed to maintain steady-state density. The gas puff was switched off at 800 ms to allow monitoring the density decay. The D_β emission at the rail limiter (Fig. 2e) being the main source of the particle balance and the CIII carbon radiation (Fig. 2c) decreased during the Li injection which lasted up to 750 ms. The decrease of CIII is indicative of the expected effect on impurity release. The amount of injected Li atoms was sufficient to cover the limiter surface by several monolayers of Li atoms. The decrease in CIII was accompanied by an increase of the continuum emission (5235 ± 6 Å pass-through range by means of a monochromator, Fig. 2f) reveals an increase of the effective charge Z_{eff} of the plasma since the electron temperature perturbation at the plasma edge was small (Fig. 2g). At 750 ms when the lithium flow into the plasma (see LiII signal) starts to decrease the CIII and D_β radiation increase. The reaction of CIII is opposite to the one when Li injection started.

D_β responded to changes of the gas flux F_{gas} during the discharge when F_{gas} was reduced for the density plateau phase at 400 ms and when it was terminated at 800 ms with a delay [4] in each case. The D_β increase is not caused by a drop in temperature which cannot be expected when the density is decreased and is also not noted (see Fig. 2g). The increase in D_β indicates that it does not emerge simply from the dissociation and ionization of hydrogen rather a complex equilibration process occurs in the neighborhood of gas valve and limiter (see Fig. 1) which involves neutral and ion collisions and possibly processes including excited molecular states. As this paper concentrates on the generation of a target plasma to start further experiments under conditions of lower recycling (possibly at the expense of a different impurity mix), the discharge section between 500 and 750 ms with the introduction of lithium in a quasi-steady-state phase is selected for further analysis (bordered by dashed lines in Fig. 2).

In the effort to explore the limits of the Li-dust technique, the Li flow was varied. The upper limit for the Li flow is shown in Fig. 3 with the help of the same traces as shown in Fig. 2. The dust input into the plasma was increased to about 2×10^{20} at/s into shot #61651. The results are shown in red curves, whereas the reference shot (in black) is the same as in Fig. 2. All features are more