Energy balance of FTU discharges with lithized walls

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INTRODUCTION

At the end of 2005 a Liquid Lithium Limiter (LLL) with capillary porous system (CPS) was tested for the first time on the high field medium size tokamak, FTU. LLL has been used as plasma facing material and as a wall conditioning technique to deposit a lithium film on the chamber walls (lithization). Liquid lithium could represent a good solution in the future fusion machines to control high heat loads and to ensure the self-regeneration of the plasma facing surface. Moreover lithium is a low Z material with very good getter properties for light impurities (oxygen and carbon) and for working gas particles, as required to minimize plasma contamination and particle recycling. The innovative concept tested on FTU and developed by Russian Federation is based on the effect of capillary forces to counteract the action of JxB forces on tearing molten lithium off the container and to refill the lithium surface faced to the plasma from an underlying liquid lithium reservoir.

In this paper, after a brief description of the CPS liquid lithium limiter and lithization procedure, the physical effects of lithization on plasma characteristics and in particular those related to the energy transport analysis are described including a comparison between lithization, boronization and full metallic walls conditions. Then the conclusions are drawn.

LLL SYSTEM AND LITHIZATION PROCEDURE

The prototype of LLL used on FTU [1] employs the same CPS configuration just successfully tested on T-11M [2]. This structure is realized as a matt from wire meshes of stainless steel 304, with pore radius 15 $\mu$m and wire diameter 30 $\mu$m that lead liquid lithium
to the side faced to the plasma from a liquid lithium reservoir. The LLL system, composed by three similar units showed in Fig. 1, is installed on a vertical bottom port of FTU and can be exposed to the edge plasma up to 2 cm inside the last closed magnetic surface (LCMS) defined by the contact with a TZM (an alloy with 98% of molybdenum) toroidal limiter. Lithization is performed by using LLL during plasma discharges as a source of lithium atoms produced by sputtering plus evaporation processes induced by plasma interaction. Three shots at $B_T=6T$, $I_p=0.5 \, MA$, linear average density $n_e=0.7 \times 10^{20} \, m^{-3}$ with LLL inserted at a distance of about 2 cm from LCMS are needed to form a lithium film thickness of about 10 monolayers, by assuming an uniform distribution of Li atoms on the chamber walls.

**PLASMA RESULTS**

In the first experimental campaign the LLL has been tested in ohmic discharges at $B_T=6T$, $I_p=0.5-0.9MA$ and $n_e$ from 0.15 up to $2.7 \times 10^{20} \, m^{-3}$. Lithization has allowed obtaining very clean plasma with a strong reduction of medium-high Z impurities such as Fe and Mo and with a prolonged gettering effect on oxygen due to the Lithium accumulation on the surfaces not directly exposed to the plasma. These results have produced low effective ion charge mostly maintained below 2.0 during all the experimental campaign (about 200 shots). As a consequence of the reduction of $Z_{eff}$, the resistive loop voltage was lower than for purely metallic walls conditions and even lower than for discharges after boronization [3]. Also the radiated power was reduced to the lowest values ever reached on FTU, between 40% -20% for all the explored plasma conditions (Fig. 2).

Another effect of lithization has been the strong modification of the recycling characteristics due to the pumping effect of Li on D₂ particles, resulting in a better control of plasma density and in a higher density limit than for boronized walls [4]

**ENERGY TRANSPORT ANALYSIS**

Transport and energy balance analysis was performed for lithized, metallic and boronized discharges with $B_T=6 \, T$, $I_p=0.5 \, MA$ and linear average $n_e=0.6 \times 10^{20} \, m^{-3}$. In
particular, a clean metallic discharge (i.e. oxygen-free) and a fresh boronized discharge without saturated walls were chosen for comparison with lithizated discharge. The analysis was made using the transport code JETTO [5] in interpretative mode as concerning electron energy transport. Experimental magnetic equilibrium, electron density profile and temperature profile were used as input of the code. Radiation profile was calculated from impurities concentrations by the cooling rate factor for each single impurity, while effective ion charge was obtained from bremsstrahlung measurements which within the error bars is consistent with the experimental resistive loop voltage. Due to the fact that ion temperature is not measured on FTU, ion temperature profile was calculated assuming neoclassical ion transport augmented by an anomaly factor of about 2.5 needed to reproduce the experimental neutron rate in ohmic discharges before lithization.

As a result of our analysis it was found out in lithizated and boronized discharges an improvement of the energy confinement time $\tau_e$ by a factor of 1.3 in comparison with metallic ones (Fig. 3). On the other hand, the transport analysis shows a reduction, even though not so remarkable, of electron thermal diffusion coefficient $\chi_e$ for lithizated discharge [3] as well as in boronized discharge in comparison to the metallic one (see Figure 4). This small reduction cannot be considered an indication of any substantial evidence of an ameliorated transport regime. This is due to the fact that the major responsible for the increase of the energy confinement time is the strongly reduced ohmic power in lithizated and boronized discharges as a consequence of reduction of the effective ion charge, $Z_{\text{eff}}$. A lower value of $Z_{\text{eff}}$ causes reduction both in ohmic input power and in output radiated power, so that the two terms contribution balance each other in the calculation of $\chi_e$. 

![Fig. 3. Energy confinement time for lithized (continuos), boronized (dashed) and metallic (dotted line) discharge.](image)

![Fig. 4. Electron thermal diffusion coefficient $\chi_e$ for lithized (continuos) and metallic (dotted) discharges.](image)
The energy confinement time $\tau_E$ as resulting from energy balance analysis, was compared with ITER97 L-mode scaling [6] and found higher by a factor between 1.19 and 1.25 for the lithizated discharge (Figure 5). The fresh boronized discharge shows an increment by about the same factor, while the metallic discharge has a value of $\tau_E/\tau_{ITER97L}$ of about 1.1, a value sensibly higher than the average for the standard FTU ohmic discharges, which is equal to 0.92 [7]. This fact is essentially due to the particularly good cleaning state of the analyzed metallic discharge where oxygen is almost completely absent.

**CONCLUSIONS**

Transport energy balance analysis has been performed among lithizated, boronized and purely metallic ohmic plasma discharges. For all these cases, values of $\tau_E/\tau_{ITER97L}$ greater than one have been found and up to 1.25 in lithizated and boronized discharges. However, it is to point out that, for boronized discharges, differently to lithizated discharges, this behaviour is observed only for the best wall conditions, i.e. a few shots after boronization with not saturated walls. In the case of metallic oxygen-free discharges this behaviour is obtained only after old lithization and/or boronization when the gettering effect of Li and B on oxygen is still present.

**REFERENCES**


[4] O. Tudisco et al., this Conference.

