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# Amelioration of plasma-material interactions and improvement of plasma performance with a flowing liquid Li limiter and Li conditioning on EAST & Experiments on FTU with a liquid tin limiter

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A. Wall conditioning and ELM control has played a crucial role in enabling access to record long H-mode pulses in EAST. Here we present new results where 1) a 2nd generation (2G) flowing liquid lithium (Li) limiter was inserted into the EAST midplane and used to mitigate plasma-materials interactions (PMI); 2) Li powder was injected to eliminate ELMs in upper-single null (USN) configuration that used the ITER-like tungsten monoblock divertor; and 3) Li granule injection was used for ELM triggering studies.

A 2G flowing liquid Li limiter was inserted into EAST and was found to be compatible with H-modes, even when placed within 1cm of the separatrix in RF heated discharges. Both the 2G and 1st generation (1G) limiters use a Cu plate for the heat sink, with a thin stainless steel (SS) coating for Li compatibility. The 2G limiter had several design improvements over the 1G limiter, including a thicker SS protective layer, two jxB pumps instead of one, an improved Li distributor manufacturing process, and surface texturing to improve wetting of the SS face. The fractional surface area that was wetted by the Li was > 80% in the 2G limiter, vs. ~30% in the 1G limiter. The heat flux exhausted by the 2G limiter was up to 4 MW/m2. In otherwise similar conditions, there was a shot-by-shot progressive reduction in Dα emission with 2G limiter insertion, culminating in short-lived ELM-free phases for the first time in EAST, with increasing τE and transient HH98y2 < 2. A 3G limiter has being fabricated out of Mo for upcoming tests.

Li powder was injected into USN H-modes using ITER-like tungsten monoblock divertor. At constant Li injection rates, the ELM elimination became progressively easier, suggesting a cumulative wall conditioning effect, as also observed with the 2G flowing liquid lithium limiter. Normalized energy confinement HH98y2 was maintained at about 1.2, well above the previous ELM elimination with Li injection on the lower carbon divertor with HH98y2 ~ 0.75. Finally ELM triggering studies with a four-chamber Li granule injector showed a clear size threshold for ELM triggering probability, as qualitatively predicted by theory. The observed threshold was similar to DIII-D experiments. ELM pacing was also observed, but the paced ELM frequency was below the 200 Hz natural ELM frequency in these discharges, preventing ELM heat flux mitigation conclusions.

B. In this paper we report experimental results obtained, for the first time in the world, in a tokamak with a liquid tin limiter (TLL). The FTU TLL was realized by using a molybdenum tube covered with Capillary Porous System (CPS) made by stripes of tungsten felt filled with tin. The TLL can be cooled by flowing air and atomized water inside a copper pipe inserted in the molybdenum tube. To test TLL, a standard FTU discharge was used with a toroidal field B_t = 5.3 T, a plasma current I_p = 0.5 MA and an electron density n_e ≤ 1.0 10^20/m^3. The thermal load on the limiter was progressively varied moving up the limiter shot by shot in the scrape-off-layer (SOL), until almost reaching the last closed magnetic surface (LCMS). The most significant results without active cooling, were obtained by increasing the heat load on the TLL by changing the average electron density from 0.6 to 1.0 10^20/m^3. The thermal load onto the TLL by Langmuir probes increased proportionally with the electron density reaching a value greater than q_LP = 15MW/m^2 for almost 1s for TLL position close to the LCMS. By looking at the temporal evolution of the IR maximum surface temperature and of the measured Sn XXI line emission monitored by the UV spectroscopy, it was deduced that tin evaporation becomes the dominant tin production mechanism when the maximum surface temperature (T_s,max) of the limiter exceeds 1300 °C up to the upper value of 1700 °C reached at the end of the pulse. A maximum heat flux of q_max=18 MW/m^2 resulted in this case by the application of the 3D finite-element code ANSYS to the real design of the limiter and of CPS. A concentration of tin of about 5.0e-04 of the electron density was deduced from the Z_eff value. By applying the JETTO code, no significant difference was found in the confinement time with respect to the case of absence of tin limiter and without degradation of the plasma performance. No droplets into plasma and no damages were observed on the TLL after the plasma exposition.

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