S3-2

S3-2: Liquid-Lithium PFC/Divertor Concept Optimization and Related R&D*

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1. Introduction

Steady-state fusion plasma heat and particle load on divertor plasma facing components (PFCs) presents major technology challenges for reactor design [1]. It has been suggested that radiative liquid lithium divertor (RLLD) concepts could provide a possible solution while potentially improving reactor plasma performance [2, 3]. The application of lithium (Li) in the NSTX PFCs resulted in improved H-mode plasma performance while maintaining essentially Li-free core plasma. Li is also shown to possess highly effective protective function for divertor PFCs. Application of thin (~ 0.1 mm thick) Li coating was sufficient to protect the LLD's delicate thin (~ 0.4 mm) moly/stainless steel surface layers bonded over ~ 2 cm thick copper substrate. With Li coating, no LLD surface metallic material such as moly was observed during plasma operations even with the divertor strike point was moved directly onto LLD. Post operation inspection also confirmed no significant damages to the LLD surfaces [4].

2. Radiative Liquid Lithium Divertor Concept

The conventional radiative divertor concept has proven to be effective in significantly reducing the high heat flux on the divertor strike points which can cause destruction/erosion of solid high-Z PFCs. However, while the divertor heat reduction is achieved, plasma confinement degradation is also observed due to increased divertor recycling. The confinement degradation is a serious obstacle, since the achievable fusion energy gain depends very strongly on the plasma confinement. The utilization of Li as a radiative element could reduce the divertor heat flux without increasing recycling. The RLLD concept was proposed to reduce the divertor heat flux via non-coronal radiation of Li in the divertor plasma as shown in Fig. 1 [2, 3]. The schematic is simplified to illustrate the basic concept, but the actual RLLD divertor chamber shape is more complex and can also have a closed divertor configuration. A closed RLLD divertor may be more advantageous from the point of view of thermal and particle separation between the main fusion chamber and the divertor chamber. The thermal isolation is beneficial from overall electrical conversion efficiency considerations, and the particle separation may help reduce potential Li migration into the main chamber. This minimizes plasma dilution and reduces overall particle recycling in the main chamber, which would help improve plasma confinement. The RLLD is placed at the bottom of the reactor chamber to be compatible with the LL handling and recycling requirement, and also to capture any impurity particles including dust generated within the reactor chamber as illustrated in Fig. 1. An active RLLD or "ARLLD" concept [3], which is based on actively controlled injection of Li closer to the divertor entrance as depicted in Fig. 1, has the advantage of inducing radiative loss well away from the divertor plate, thus improving the chance of spreading the radiative heat more evenly throughout the divertor chamber wall. Active Li injection from the divertor side wall also has the advantage of a relatively narrow divertor plasma channel (short radial travel distance) for rapid Li delivery for a closed divertor chamber. So, it can quickly respond to relatively fast changing divertor heat load events such as major ELMs. For providing effective divertor pumping, the LL flow is introduced at the upper part of the RLLD near the divertor throat area at multiple toroidal locations, and the LL flows down the RLLD side wall as a thin film via gravity action. The thin LL film ≤ 0.1 mm thick thus formed should provide very effective pumping (or entrapment) of the working gases, impurities, and dust generated within the reactor chamber. The LL temperature as it enters at the top of the divertor wall should be ~ 200°C

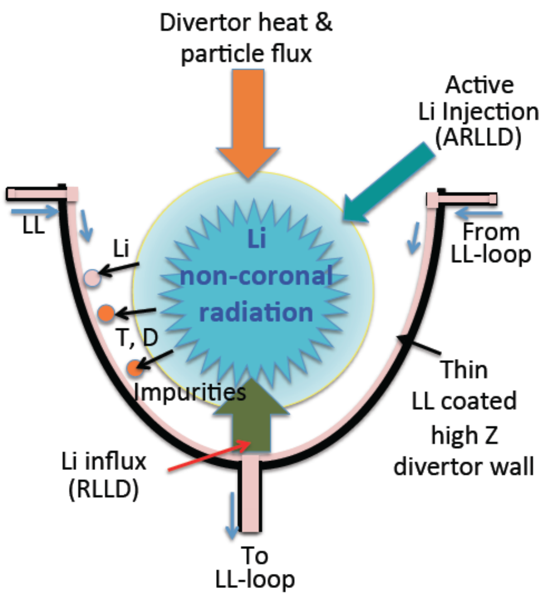

Fig. 1. A simplified schematic of RLLD/ARLLD low collisionality radiative divetor concept.

so that LL can effectively pump tritium and deuterium (T & D). As it flows down the divertor wall, it may be heated by the plasma radiation, but due to its very thin thickness ~ 0.1 mm, it should retain the temperature of its solid PFC substrate which is actively cooled. This effective LL pumping by a very thin LL layer was also observed in EAST recently [7]. It should be noted that the RLLD chamber wall temperature in the 200 – 400 °C range is significantly lower than that envisioned for a fusion reactor first wall at ~ 600 – 700°C. The hot reactor first wall should keep the wall surfaces clean from the working gas, and also from impurities including Li and Li-related compounds. The LL flowing down the divertor side wall accumulates at the bottom of RLLD, at the location of the divertor strike point. By placing the LL surfaces in the path of the divertor strike point, the LL is evaporated from the surface through sputtering, evaporation, and chemical processes. The evaporated Li is quickly ionized by the plasma, and the ionized Li ions can radiate strongly, reducing the heat flux to the divertor strike point surfaces and protecting the substrate material. Perhaps the last line of defense for the high-Z divertor PFC substrate is the LL evaporation from the LLD surfaces. Through evaporation, Li can carry some heat away from the material surfaces analogous to the way the latent heat of vaporization clamps the surface temperature rise. The evaporated Li could also form a Li vapor cloud in front of the divertor surface and subsequent ionization and radiation provide powerful additional protection.

3. Liquid Lithium Loop System:

Finally, to utilize any LL PFCs/divertor system in a fusion reactor system, it is necessary to bring the "used" LL out of the LL divertor chamber to remove some level of T/D and other impurities including dust particles. Continuous T recovery of ~ 0.5 g/sec is necessary since most of the injected T (~ 99%) is not consumed by the fusion reaction and exhausted into the divertor chamber. T exhausted therefore must be removed and recycled back into the plasma for sustained fusion reaction. Since Li is chemically active, it is also necessary to remove other contaminants including deuterium and impurities/dust. While this continuous cleaning is necessary for any LL system, such a system would help keep the reactor vacuum chamber clean which is highly beneficial for the safe fusion powerplant operations. For this reason, a relatively modest LL loop system operating at ~ 1 l/sec flow speed has been proposed as shown in Fig. 2 [9]. Some new technical solutions for a timely recovery of T from LL to support the T fuel cycle and maintain the T inventory to an acceptable level were proposed. Operating the LL-loop system at lower temperature is generally favorable for T inventory to maintain low T saturation level. In terms of LL safety, it is also important to operate the LL system below ~ 400 °C to reduce long term corrosion issues, since Li corrosion rate accelerate significantly at higher temperatures.

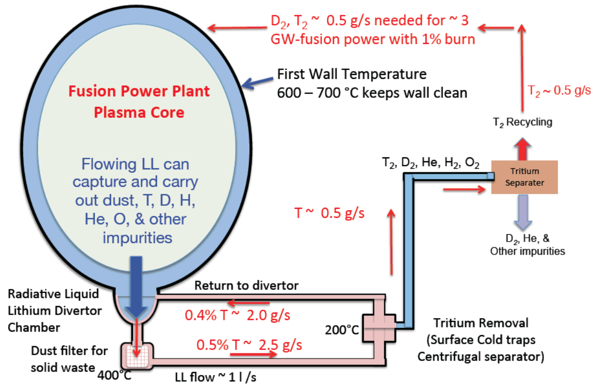

Fig. 2. A schematic of a LL-loop for removing dust and tritium/impurities from the power plant vacuum and divertor chamber.

4. NSTX-U Li Concept Optimization and R&D

Various Li & LLD related R&Ds are being performed to optimize LLD for NST-U. If the Li contamination of the main chamber is an issue, one might consider additional isolation chambers for the LLD concept such as the "vapor box" concept [8]. By creating additional closed chambers, one could envision reducing the Li migration into the main chamber. If the peak divertor heat flux reaching the solid PFC substrates cannot be reduced to an acceptable level (≤ 5 MW/m^2), it may require an active transport of the LL across the divertor strike point. This "fast" flowing LL is being investigated using various test laboratory facilities. Those LLD R&D activities are carried out to support an optimization of the eventual LLD implementation on NSTX-U and future fusion reactors.

***ACKNOWLEDGMENTS** - This work was supported by DoE Contract No. DE-AC02-09CH11466. The author thanks valuable contributions from Drs. Y. Hirooka, M. Jaworski, H. Kugel, R. Maingi, C. Skinner, S. Kaye, J. Menard, R. Goldston, R. Majeski, E. Egemen, M. Bell, D. Mansfield, F. Scotti, T. Gray, D. Andruczik, and D. Ruzic.

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