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Investigations on interactions between the flowing liquid lithium limiter and plasmas

J. Ren[a], G.Z. Zuo[a], J.S. Hu[a,*], Z. Sun[a], J.G. Li[a], L.E. Zakharov[b], D.N. Ruzic[c], W.Y. Xu[c]

[a] Institute of Plasma Physics, Chinese Academy of Sciences, 230031 Hefei, China
[b] USA Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA
[c] University of Illinois at Urbana-Champaigns, Urbana, IL 61801, USA

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ABSTRACT

Two different designs of flowing liquid lithium limiter were first tested for power exhaust and particle removal in HT-7 in 2012 autumn campaign. During the experiments, the reliability and compatibility of the limiters within Tokamak were experimentally demonstrated, and some positive results were achieved. It was found that the flowing liquid lithium limiter was effective for suppressing H concentration and led to a low ratio of H/(H + D). O impurity was slightly decreased by using limiters as well as when using a Li coating. A significant increase of the wall retention ratio was also observed which resulted from the outstanding D particles pumping ability of flowing liquid lithium limiters. The strong interaction between plasma and lithium surface could cause lithium ejection into plasma and lead to disruptions. The stable plasmas produced by uniform Li flow were in favor of lithium control. While the limiters were applied with a uniform Li flow, the normal plasma was easy to be obtained, and the energy confinement time increased from ~0.025 s to 0.04 s. Furthermore, it was encouraging to note that the application of flowing liquid lithium limiters could further improve the confinement of plasma by ~10% on the basis of Li coating. These remarkable results will help for the following design of flowing liquid lithium limiter in EAST to improve the plasma operation.

1. Introduction

With exceptional particle pumping properties and low Z, application of Li in fusion reactors has been tested in Tokomaks and other magnetic confinement devices for many years [1–4]. Li coating has been regarded as an effective method to reduce impurities and edge particle recycling in TFTR, NSTX, TJ-II and EAST [5–8]. The main results from Li coating are summarized as follows: first, the outstanding ability of pumping particles of Li results in very low impurity and recycling level in plasma; second, most of Li atoms are ionized and radiate at the plasma edge due to the low Z and low ionization energy to avoid the contamination on core plasma; third, ICRF heating efficiency improves according to the minority ions heating mode due to the low H/(H + D) by Li coating; fourth, Li coating can suppress MHD and ELMs in plasma; finally, it also can reduce the H-mode power threshold and improve the plasma confinement. However, a future fusion device still faces several issues related to materials, such as stringent power exhaust capabilities and material lifetime. Applying liquid Li as plasma facing components (PFC) is a potential solution for future fusion device and has been tested in many Tokamak devices. Using a toroidal liquid Li pool limiter on CDX-U, plasma discharges with a lower loop voltage, wall recycling and impurities level were achieved [9]. In T-11M, a lithium limiter with capillary-pore system (CPS) has been demonstrated for its ability in confining the liquid Li in the CPS during disruption and protecting PFC from high power bombarding during quasi steady state and disruptions regimes due to Li non-coronal radiation, which resulted in clean ($Z_{eff} = 1$) deuterium plasma discharges and the radiation losses concentrating in a relatively thin boundary layer [10]. In FTU, a liquid Li limiter system composed by three similar units could withstand 5 MW/m^2 heat load, Greenwald limit and higher electron temperature were obtained [11].

Liquid Li limiters have been tested on HT-7 since 2009 [12–14]. Using a movable liquid Li limiter with free surface, increased plasma confinement, suppressed impurities and reduced recycling during ohmic plasma discharges were observed as well as Li coating. Confined surface and suppressed Li splashing during the disruption regimes was achieved by application of a Li limiter with CPS. Furthermore, a re-filling liquid Li limiter experiments on HT-7 confirmed the possibility of driving the Li flow by Ar pressure. In

* Corresponding author. Tel.: +86 055165591353.
E-mail address: hujs@ipp.ac.cn (J.S. Hu).

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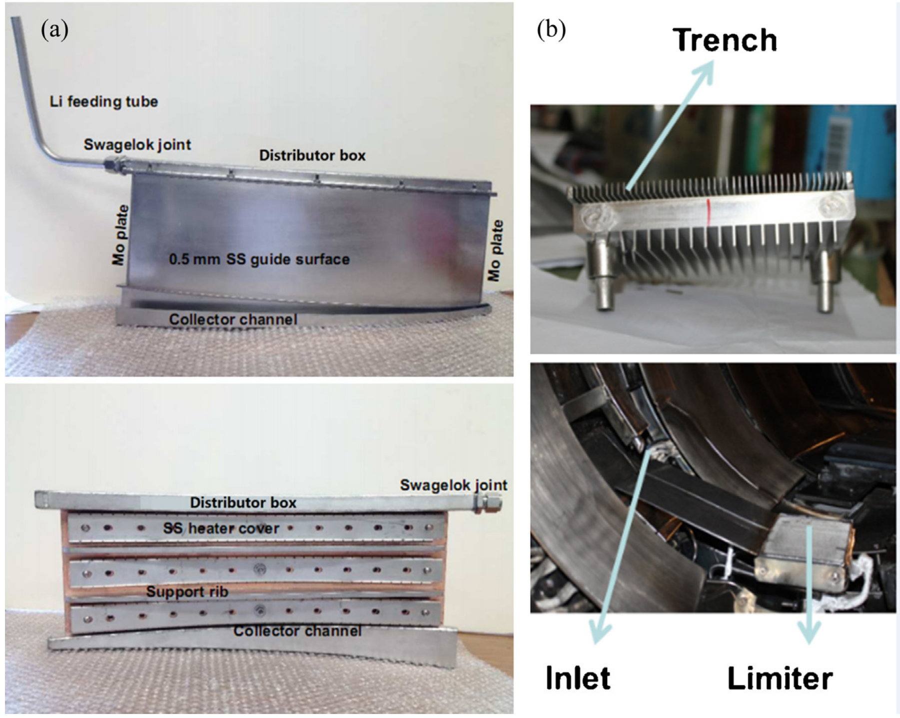

Fig. 1. Structures of the FLiLi limiter (a) and LIMIT limiter (b).

this paper, we investigate two different types of limiters which are termed as the FLiLi limiter and the LIMIT limiter respectively in order to study the compatibility with plasma and interaction between the flowing liquid Li limiter and plasma.

2. HT-7 experiment

HT-7 was a middle size Tokamak with major radius $R = 1.22$ m and minor radius $a = 0.27$ m. A toroidal limiter located at the bottom of the vacuum chamber and a belt limiter installed on the high-field side had a total surface area of 1.28 m^2. Both of them were Mo materials in the 2012 campaign.

During 2012 HT-7 campaign, more than 700 ohmic plasma discharges were demonstrated with a discharge flattop in the range of 0.5–2 s. Two different designs of flowing liquid Li limiters, FLiLi limiter and LIMIT limiter, were tested in this campaign (see Fig. 1) [15]. The operation temperatures of both of the two limiters were above 300 °C. FLiLi limiters using a thin flowing film concept were installed on the mid-plane of the high-field side. This kind of FLiLi limiters had a special distributor with multiple channels to guide the liquid lithium from the distributor to the SS guide plate surface according to the magnetohydrodynamic (MHD) effect of the pressure drop when the liquid Li was moving across the channels in a magnetic field. The pressure drop along the channels larger than that inside the distributor box guaranteed a uniform supply from the channels to the guide surface. The minimal magnetic Reynolds and Hartmann numbers due to the designed velocity of flow less than 1 cm/s and 0.1 mm flow thickness resulted in a negligible interaction of the free surface flow with the magnetic field. For HT-7, the typical particle flux to FLiLi limiter surface is 3.3×10^{20}/s approximately. Assuming Li absorbing capacity as 10% (atomic), removing the particle flux from limiter would require replenishment of 3.3×10^{21}/s atoms which is satisfied with the designed velocity. The heat flux from the plasma can be effectively removed using the heat sink with an actively cooling system. Furthermore, a self-sacrificial liquid lithium surface can protect PFC from the disruptions and ELMs due to its rapid evaporation. Such kind of FLiLi limiter was experimentally demonstrated in HT-7, in which a uniform liquid Li film slowly crept along the guide surface driven by Ar pressure.

The other flowing liquid Li limiter was using the thermoelectric magnetohydrodynamic (TEMHD) effect to drive the liquid Li flow in a stainless tile with Li-metal infuse trenches (LIMIT). This LIMIT was installed at the bottom of the vacuum chamber to face the heat flux (>100 kW/m^2) during the ohmic plasma discharges. A thermoelectric device creates voltage when there is a different temperature on liquid Li and SS tile. This thermoelectric voltage creates an electric current, which has a component perpendicular to the SS surface of limiter and drives the lithium flow by $J \times B$ force. The velocity of liquid Li in the trench can be assessed as: $\bar{u} = \left(P/B\right) \times \left(\mathrm{d}T/\mathrm{d}z\right) \times \left(\left(H\alpha - \tan\mathrm{h}\left(H\alpha\right)\right)/\left(H\alpha + C\tan\mathrm{h}\left(H\alpha\right)\right)\right)$,, where P is the difference of the Seebeck coefficient between SS and Li, B is the magnetic field intensity, $\mathrm{d}T/\mathrm{d}z$ is the gradient of temperature and $H\alpha$ is the Hartmann number. Therefore, the average velocity of Li flow in HT-7 is about 4.2 cm/s [16]. During the application of LIMIT in HT-7, it was observed that the liquid Li flow near plasma touched area had a velocity about 3.7 ± 0.5 cm/s along the trenches driven by $J \times B$ force, which was approximately in accordance with the estimations.

3. Surface control related to plasma performance

It has been reported that too much Li influx into the plasma would radiate the power to the edge plasma from the core and induce the thermal instability at the edge [17]. Mostly disruptions follow the boundary MHD instability which happens simultaneously with an increased Li emission. This is the critical disruption point. The current from SOL and the induced current in liquid Li have two components, which are normal and parallel to the limiter surface. The $J_{\|} \times B_p$ force points to core plasma and induces the Li ejection from the limiter surface, when the thinner Li film is in favor of resisting electromagnetic forces. The current normal to the limiter combined with the plasma wind drives the Li droplet moving along the poloidal + I_p direction. Liquid droplets ejection and

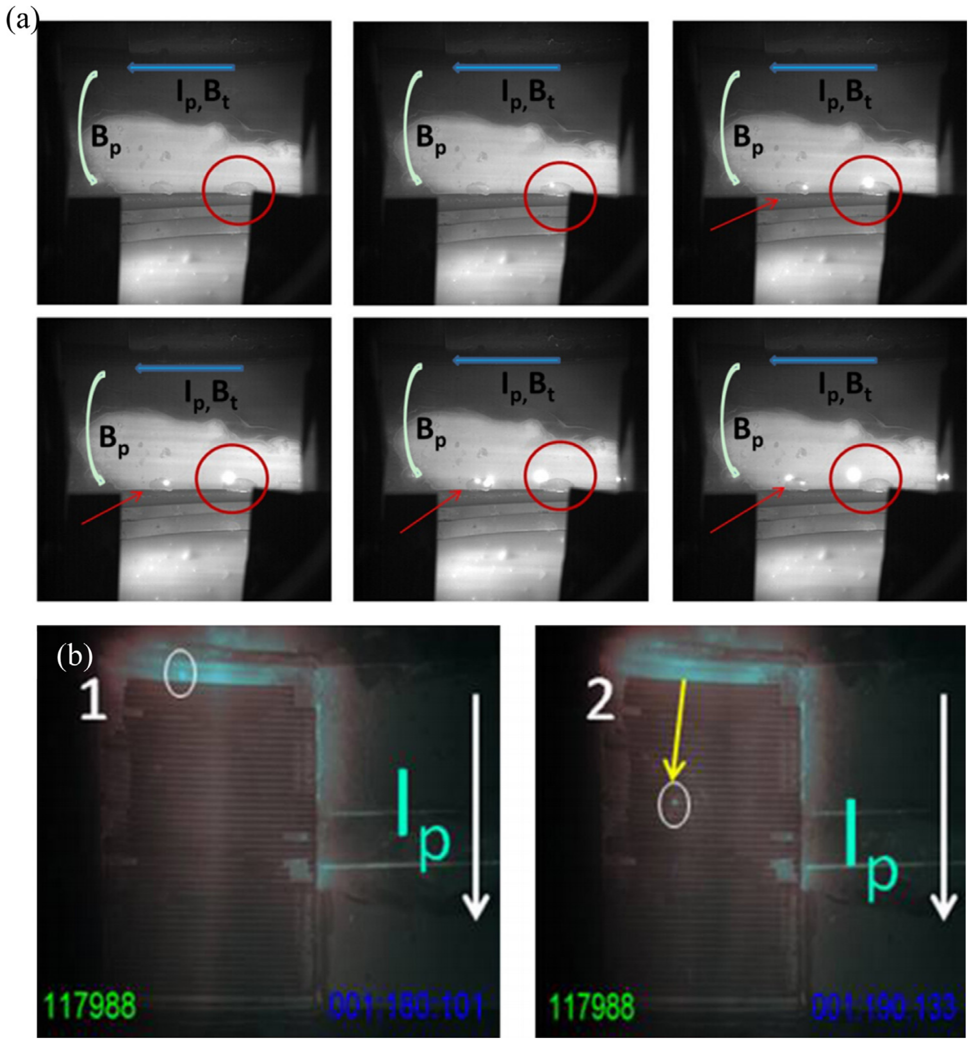

Fig. 2. Li droplet ejected from limiters by electromagnetic forces, (a) FLiLi limiter and (b) LIMIT limiter.

ionization in plasma are the main sources of Li emission. It was noted that liquid Li can be ejected into plasma during the plasma discharges, especially during the plasma current ramp up phase and when disruption occurs. As shown in Fig. 2, it was observed that a Li droplet pulled out from a small area where concentrated Li was significantly larger than elsewhere and accelerated by electromagnetic forces. The initial movements of Li droplet emitting from FLiLi limiter and LIMIT limiter were both along the direction of plasma. It was encouraging to see that even there were a mass of liquid lithium exposed on the plasma facing surface of LIMIT limiter, only one small droplet emitted from the LIMIT limiter. This showed that the trenches on the LIMIT limiter can prevent concentrated Li from injection due to $J_{\|} \times B_p$ force. For FLiLi limiter, the interesting thing was that the plasma performance responded sensitively to different temperatures of Li feeding pipe, in the case of an un-uniform Li flow on the limiter surface. As shown in Fig. 3, the disruption plasma discharges only occurred when the temperature of feeding pipe is above 180 °C which is the melting point of Li. Because when the temperature of feeding pipe was below 180 °C, the supply of Li would be suppressed and even interrupted. So the amount of Li ejection from limiter surface was decreased, which resulted in normal plasma discharges. This phenomenon wasn't observed in the flowing liquid Li limiter with a uniform Li flow. Too much Li ejection would disrupt the plasmas, and a uniform flow could resist Li ejection during plasma discharges, even during the plasma current ramp up phase and disruption.

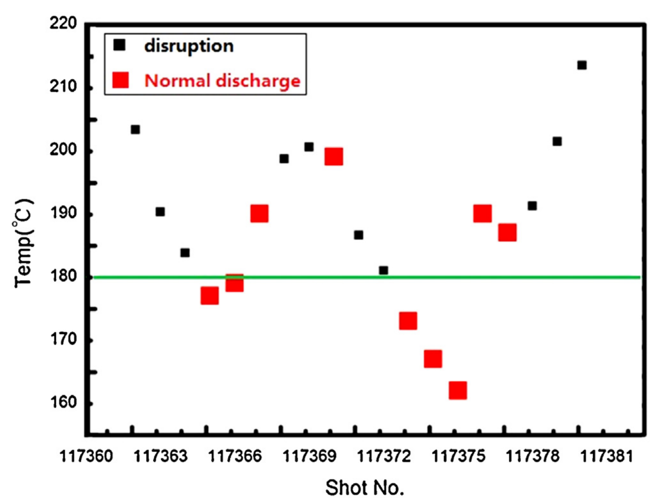

Fig. 3. The influence of temperature on the plasma discharge condition.

The basic parameters of two typical Ohmic shots were illustrated in Fig. 4, shot 117364 and 117365 with identical plasma current I_p = 120 kA. During the Shot 117364, the temperature of Li feeding pipe was 184 °C which is high enough for the liquid Li to flow into the distributor box. With increasing LiI line emission,

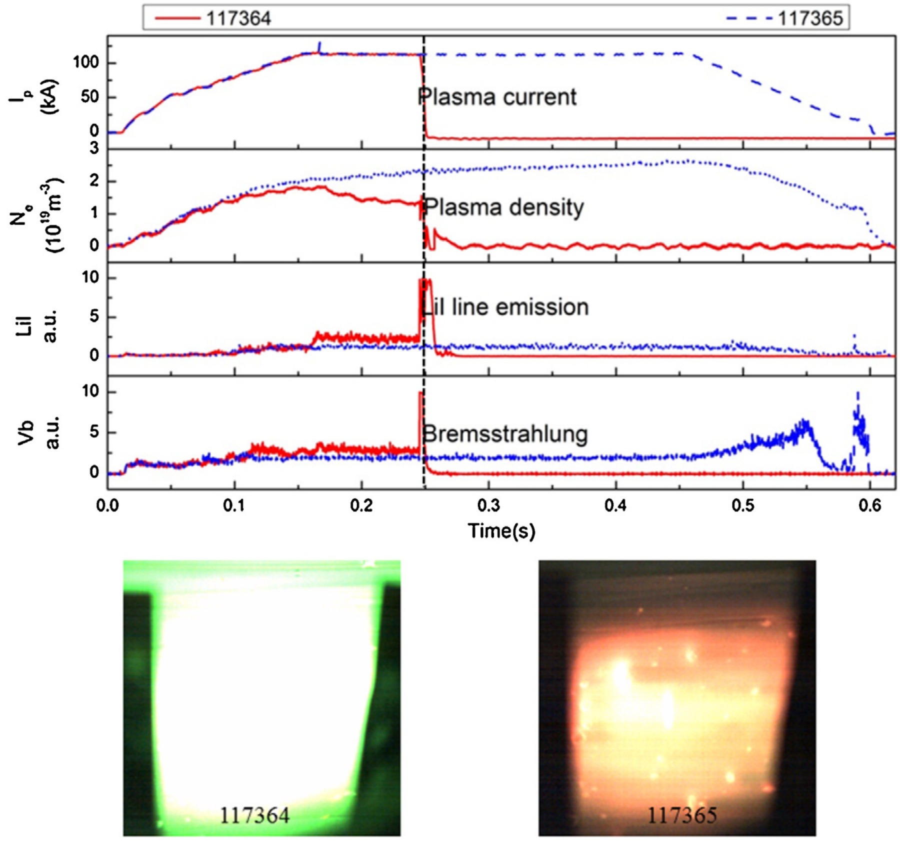

Fig. 4. Comparing between normal shot and disrupt shot.

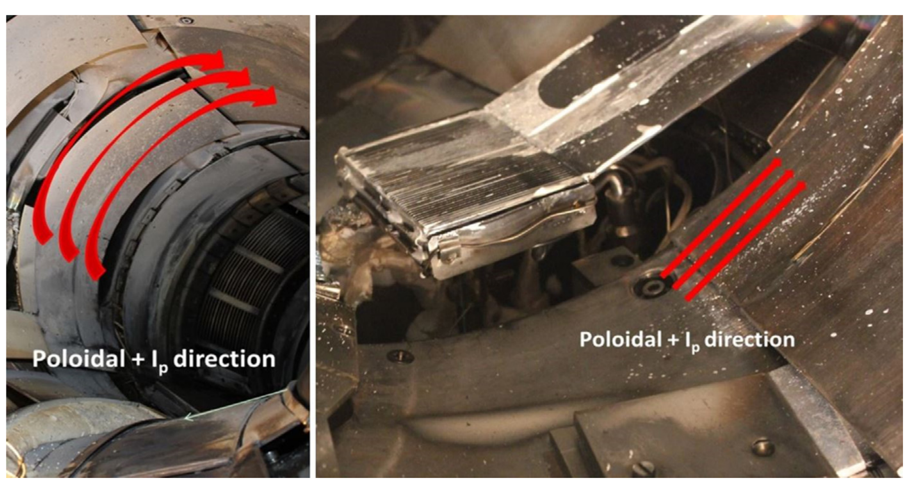

Fig. 5. The picture of flowing liquid lithium limiter and trace of lithium emission after experiment.

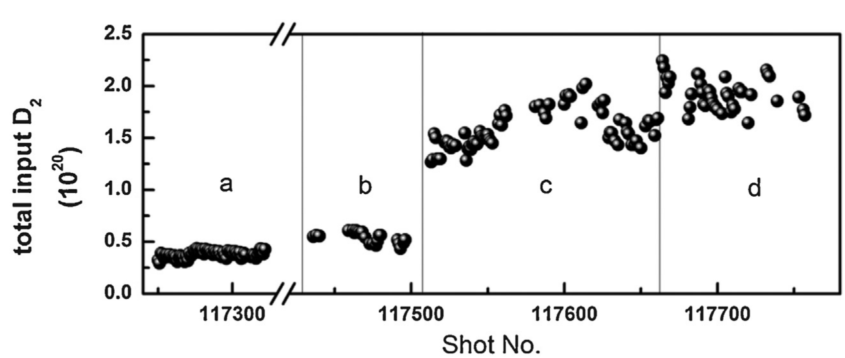

Fig. 6. Evolution of total input D_2 as a function of discharge number, (a) Mo limiter, (b) FLiLi limiter without Li coating, (c) FLiLi limiter with Li coating, (d) Li coating.

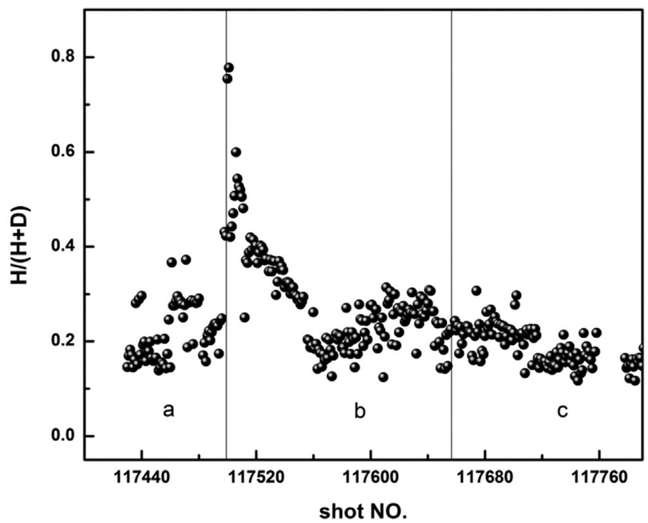

Fig. 7. Evolution of H/(H + D) ratio as a function of discharge number, (a) FLiLi limiter without Li coating, (b) FLiLi limiter with Li coating, (c) Li coating.

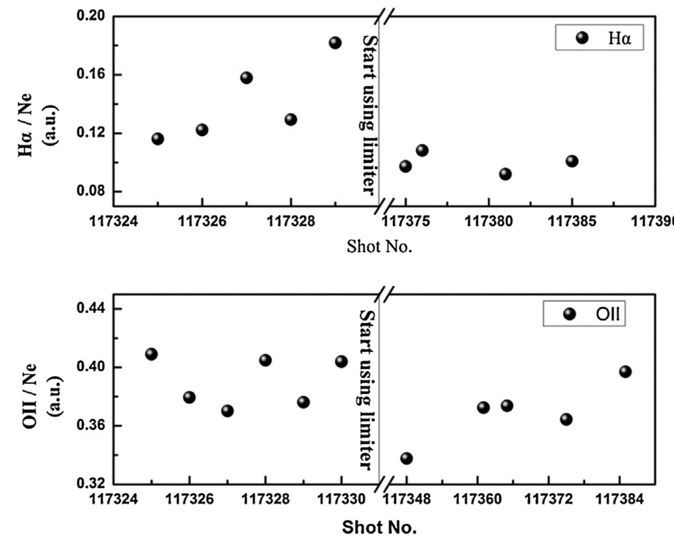

Fig. 9. Evolution of Hα and OII emission as a function of discharge number.

the density of plasma was decreased due to the absorption capacity of liquid Li. And it was found that LiI line emission abruptly erupted due to a large number of lithium ejection from FLiLi limiter, when plasma density was slightly increased caused by fueling of Li, and bremsstrahlung radiation was also increased quickly, and plasma was disrupted due to the strong radiation level. The LiI line emission saturated and maintained for about 0.04 s after disruption. These indicated that strong lithium emission led to plasma disruption, and then plasma disruption would further enhance the lithium emission from surface of FLiLi limiter. In contrast, the shot 117365 with the temperature of 177 °C on Li feed pipe showed a low LiI lime emission and a normal discharge.

After the HT-7 experiment, Lithium deposited on vessel wall was oxidized to a stable compound (Li_2CO_3) after the vacuum vessel was opened and exposed to air. As shown in Fig. 5, it was found that most of the white lithium spots were distributed along poloidal + I_p direction near to the two flowing liquid lithium limiters up to a range of 1m. The distribution of lithium spots also showed a lot of liquid lithium droplets were ejected from limiter surface driven by electromagnetic forces combine with the plasma wind.

4. H/H + D and retention

As it is shown in Fig. 6, before the application of FLiLi limiter, the amount of input D_2 was about 3.5×10^{19} under the condition of full Mo limiter. Since the start to use the FLiLi limiter, the out gas from the high temperature limiter and the absorbed fuel by the lithium competed with each other and affected the total amount of input. While using the FLiLi limiter without Li coating, the amount of input D_2 was slightly increased. Because of strong absorption ability by Li coating, it was noted that more input D_2 was needed to guarantee the density of plasma when using the FLiLi limiter with Li coating. After stop using the FLiLi limiter, the amount of input D_2 was slightly increased further due to the less out gas from the

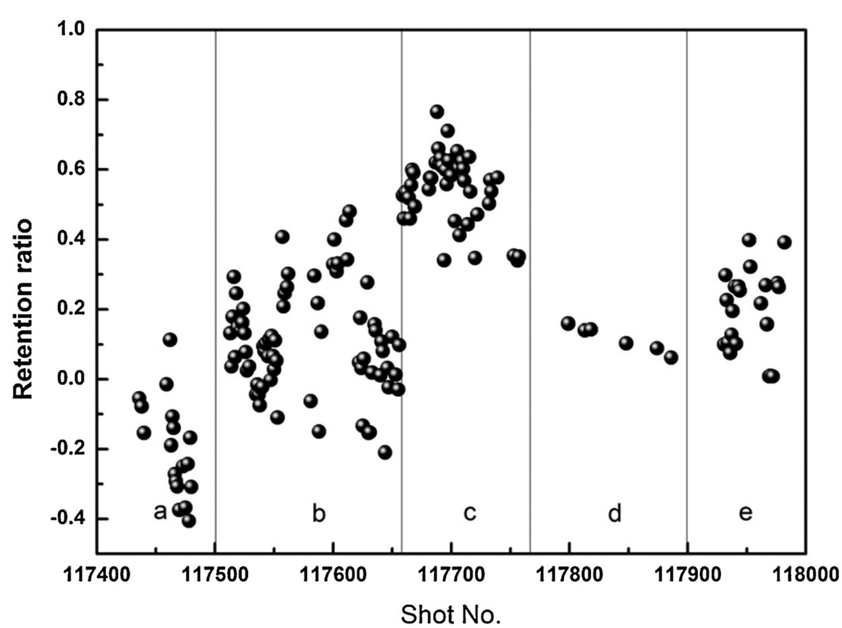

Fig. 8. Evolution of retention ratio as a function of discharge number, (a) FLiLi limiter without Li coating, (b) FLiLi limiter with Li coating, (c) Li coating (d) Mo limiter and (e) LIMIT limiter.

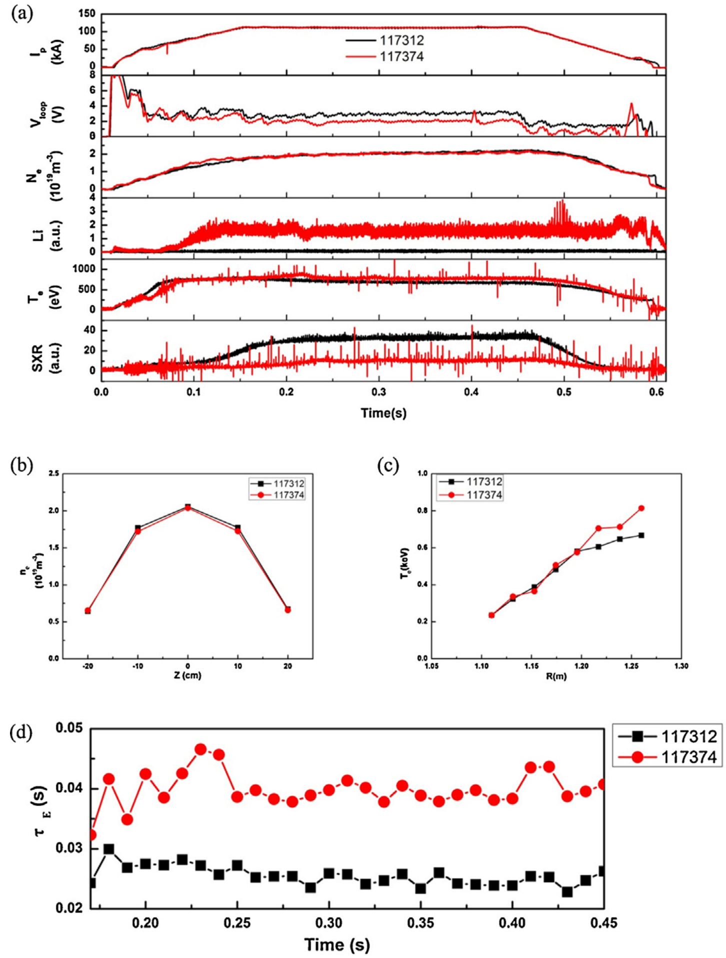

Fig. 10. Comparison of two discharges, #117312 shot was the Mo limiter discharge and # 117374 shot employed FLiLi limiter, (a) plasma current I_p, loop voltage V_{loop}, plasma density N_e, Li emission LI, core electronic temperature T_e and soft X-ray emission in core SXR, (b) profile of plasma density, (c) profile of electronic temperature and (d) energy confinement time.

limiter. These indicated that baking the limiter before the operation was necessary to avoid excess out gas from the flowing liquid lithium limiter surface.

It was also found that H/(H + D) ratio was rapidly increased after using the limiter and gradually reduced according to the strong pumping ability of Li film. From Fig. 7, it appeared that out gas from the limiter surface caused by heating lead the H/(H + D) ratio to rise to nearly 0.8. Because the H_2 was only released from walls while D_2 was from fueling, H/(H + D) ratio ultimately reduced to ~0.2 during the using of FLiLi limiter which was close to 0.15 while using the Li coating. It indicated that using the flowing liquid Li limiter could reduce H/(H + D) ratio as well as Li coating which was good for ICRF with H minority heating mode.

Fuel retention is a critical issue in the selection of plasma facing materials (PFM) for future fusion device. In HT-7, gas balance measurements of retention during the plasma discharges in Tokamak have been carried out. As it is shown in Fig. 8, it can be found that when FLiLi limiter was used without Li coating, out gas from the limiter was extremely intensive and resulted in the negative retention ratio. That is because the FLiLi limiter wasn't preheated before the Li operation and sufficiently covered by liquid Li film. But retention ratio with the FLiLi limiter and Li coating showed a better result that ~20% retention ratio was obtained during the plasma discharges. It might be due to that the Li film on the first wall by Li evaporation has an outstanding pumping ability. Besides, a large area uniform Li film on the limiter can suppress out gas and absorb the fuel immediately. Without the influence of the out gas caused by heating the limiter, retention ratio was obviously higher than using limiters. In general, both flowing liquid Li limiter and Li coating can absorb D_2 efficiently; however, out gas from the limiter surface has a large impact on it.

5. Impurities

As we know, Li is a very active element due to its excellent ability in pumping H and absorbing O which can significantly reduce the impurity level. Many fusion devices had observed that impurities were suppressed by application of Li. The evolution of *Hα* emission and OII emission was shown in Fig. 9, and it can be noted that *Hα* and OII emission was significantly reduced after starting operation of the FLiLi limiter. For the self-refresh mode of FLiLi surface, it can be expected that continuously pumping the impurities overcome the limit of Li coating lifetime.

6. Confinement

From the decreased impurities level in plasma discussed before, it can be expected an improved confinement according to reduced bremsstrahlung of high Z impurities. Also by comparing the retention ratio in different situation, it was found that retention ratio was significantly increased when flowing liquid Li limiters were used. This indicated the reduction of the recycling between plasma and wall in the edge, which would lead to higher edge temperature. Furthermore, a flattened temperature would lead to a decreased

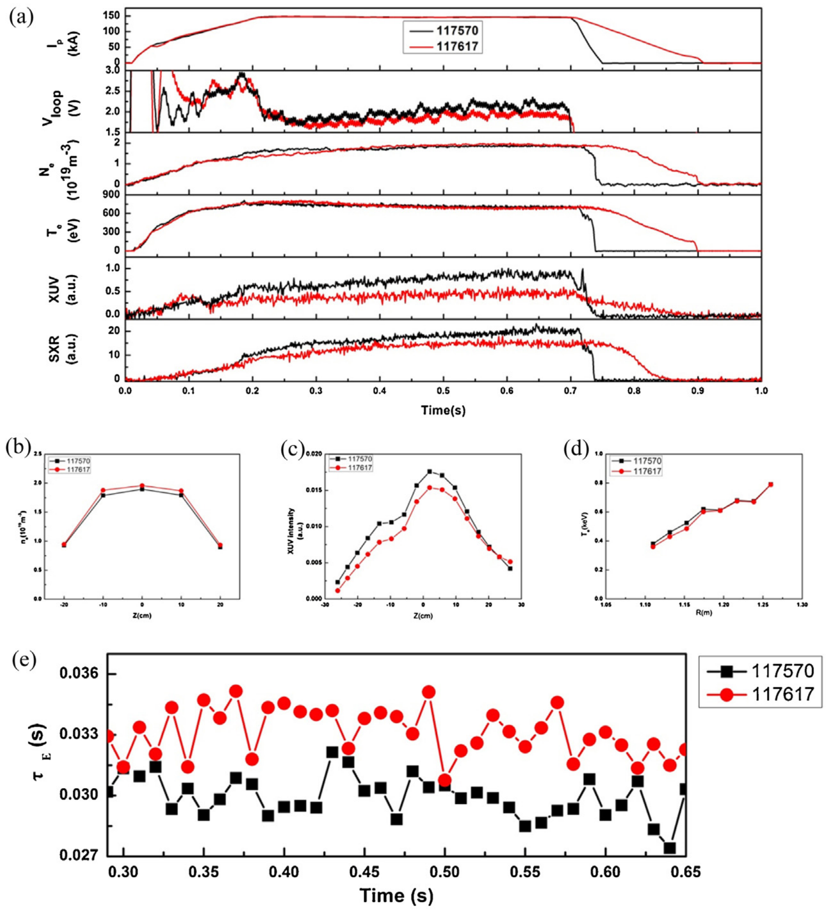

Fig. 11. Comparison of two discharges, #117570 shot was the Mo limiter discharge after Li coating and # 117617 shot employed limiter, (a) plasma I_p, loop voltage V_{loop}, plasma density N_e, core electronic temperature T_e, XUV emission and soft X-ray emission SXR in core, (b) profile of plasma density, (c) profile of XUV emission, (d) electronic temperature and (e) energy confinement time.

turbulence driven by temperature gradients. The application of flowing liquid Li limiter in HT-7 made a big improvement in confinement [18]. As shown in Fig. 10, no. 117312 shot was the Mo limiter discharge and No. 117374 shot employed FLiLi limiter. The two examples were selected because they had identical plasma current I_p = 110 kA and plasma density profile. The distinct Li emission during the discharge with FLiLi limiter showed a strong interaction between the limiter and the plasma. Compared with the discharge with Mo limiter, it was found that loop voltage reduced from ~3.3 V to ~2.6 V and soft X-ray emission was significantly reduced while using the FLiLi limiter. Especially electron temperature in the core plasma was increased. The energy confinement time of two

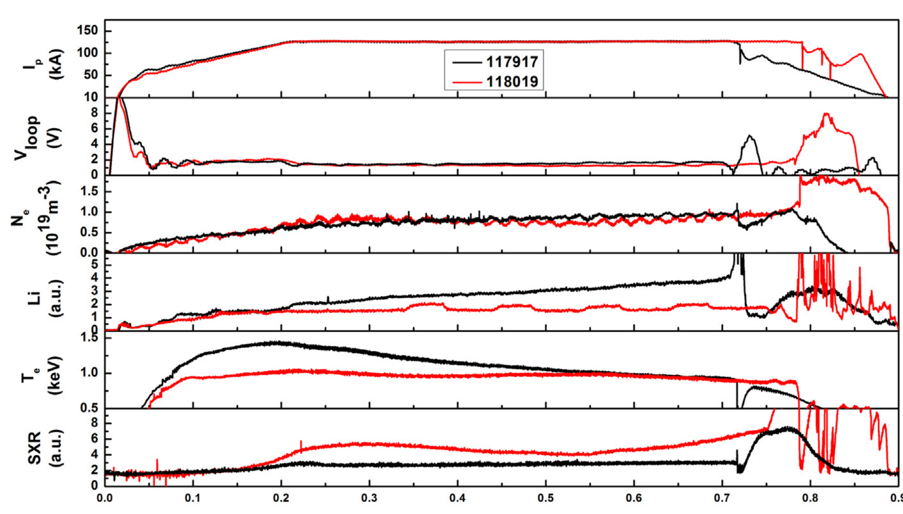

Fig. 12. Comparison of two discharges, #117917 shot employed LIMIT limiter discharge and # 118019 shot was the Mo limiter, plasma I_p, loop voltage V_{loop}, plasma density N_e, Li emission LI, core electronic temperature T_e and soft X-ray emission SXR.

discharges was calculated according to $\tau_E = W_{\text{in}}/P_{\text{in}}$, where $W_{\text{in}} = 3/2 \times \int N_e \times (T_e + T_i)\,\mathrm{d}v$ is the stored energy and $P_{\text{in}} = I_{\text{p}} \times V_{\text{loop}}$ is the input power [19]. It can be observed that the energy confinement time increased from ∼0.025 s to 0.04 s with the FLiLi limiter.

As shown in Fig. 11, no. 117570 shot was the Mo limiter discharge after Li coating and No. 117374 shot employed Li limiter after Li coating. It was found that with identical plasma current I_p = 145 kA and slightly decreased plasma density due to Li coating, when using the FLiLi limiter, loop voltage was reduced from ∼2.0 V to ∼1.9 V. There was no significant change in electron temperature on the basis of Li coating. Also it was obvious that both XUV emission and soft X-ray emission were reduced while using the Li limiter. The XUV emission profile showed that the emission from the core was significantly reduced, which indicates the improved confinement of the core plasma. On the other hand, the emission in the edge didn't change too much. This was good for the reduction of the peak value of incoming flux to the first wall. It was also observed that the energy confinement time with Li coating is longer than the Mo limiter without Li coating. The application of Li limiter after Li coating still made the energy confinement time increased form ∼0.03 s to ∼0.034 s. However, this was shorter than that only using the Li limiter without Li coating. The reason of this was not identified, it may be due to that this discharge was beyond the effective lifetime of lithium film.

As shown in Fig. 12, no. 117917 shot employed LIMIT limiter and No. 118019 shot was the Mo limiter discharge. Both two shots had the identical plasma current, plasma density and loop voltage. During using of the LIMIT limiter, it was found the electronic temperature in core increase and the soft X-ray emission in core decreased. Those also supported that employing LIMIT limiter in Tokamak can improve the confinement of plasma.

7. Summary

Two different designs of flowing liquid Li limiter were experimental tested in HT-7. During the campaign, compatibility between the flowing liquid Li limiter and Tokamak had been successfully demonstrated. Besides, some dramatic results were achieved. It was found that H concentration was effectively suppressed as well as O impurity by using the flowing liquid Li limiter. It's also observed a significant increase of wall retention ratio and reduction of H/(H + D) ratio which resulted from the outstanding pumping ability of flowing liquid lithium limiters. Ejection of lithium caused by strong $J \times B$ force had been restrained by uniform Li flow film. While using the limiters with a uniform Li flow, the normal plasma discharges were easy to obtain. Furthermore, increase of core electron temperature and reduction of soft X-ray emission was achieved while using the flowing liquid Li limiter. Energy confinement time was increased from ∼0.025 s to 0.04 s. It was worth to emphasize that the application of flowing liquid lithium limiters could further improve the confinement of plasma ∼10% on the basis of Li coating. Recently, a new flowing liquid lithium limiter system which was guided by those remarkable results in HT-7 had been prepared to be tested in EAST.

Acknowledgements

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References

[1] M. Ono, M.G. Bell, R. Kaita, H.W. Kugel, J.W. Ahn, J.P. Allain, et al., Recent progress of NSTX lithium program and opportunities for magnetic fusion research, Fusion Eng. Des. 87 (10) (2012) 1770–1776.
[2] A.A. Tuccillo, L. Amicucci, B. Angelini, M.L. Apicella, G. Apruzzese, E. Barbato, et al., Overview of FTU results, Nucl. Fusion 51 (9) (2011), 094015 (11pp).
[3] G.S. Xu, B.N. Wan, J.G. Li, X.Z. Gong, J.S. Hu, J.F. Shan, et al., Study on H-mode access at low density with lower hybrid current drive and lithium-wall coatings on the EAST superconducting tokamak, Nucl. Fusion 51 (7) (2011), 072001 (6pp).
[4] S.V. Mirnov, Experiments at the T-11M device in support of the tokamak concept with closed Li cycle, Fusion Eng. Des. 85 (6) (2010) 919–923.
[5] D.K. Mansfield, K.W. Hill, J.D. Strachan, M.G. Bell, S.D. Scott, R. Budny, et al., Enhancement of tokamak fusion test reactor performance by lithium conditioning, Phys. Plasmas 3 (5) (1996) 1892–1897.
[6] M.G. Bell, H.W. Kugel, R. Kaita, L.E. Zakharov, H. Schneider, B.P. LeBlanc, et al., Plasma response to lithium-coated plasma-facing components in the National Spherical Torus Experiment, Plasma Phys. Controlled Fusion 51 (12) (2009), 124054 (12pp).
[7] F.L. Tabares, M.A. Ochando, F. Medina, D. Tafalla, J.A. Ferreira, E. Ascasibar, et al., Plasma performance and confinement in the TJ-II stellarator with lithium-coated walls, Plasma Phys. Controlled Fusion 50 (12) (2008), 124051 (9pp).
[8] G.Z. Zuo, J.S. Hu, J.G. Li, Z. Sun, D.K. Mansfield, L.E. Zakharov, Lithium coating for H-mode and high performance plasmas on EAST in ASIPP, J. Nucl. Mater. 438 (2013) S90–S95.
[9] R. Majeski, S. Jardin, R. Kaita, T. Gray, P. Marfuta, J. Spaleta, et al., Recent liquid lithium limiter experiments in CDX-U, Nucl. Fusion 45 (6) (2005) 519–523.
[10] S.V. Mirnov, E.A. Azizov, V.A. Evtikhin, V.B. Lazarev, I.E. Lyublinski, A.V. Vertkov, et al., Experiments with lithium limiter on T-11M tokamak and applications of the lithium capillary-pore system in future fusion reactor devices, Plasma Phys. Controlled Fusion 48 (6) (2006) 821–837.
[11] G. Mazzitelli, M.L. Apicella, A. Alexeyev, F. Team, Heat loads on FTU liquid lithium limiter, Fusion Eng. Des. 86 (6–8) (2011) 580–583.
[12] G.Z. Zuo, J.S. Hu, J.G. Li, N.C. Luo, L.E. Zakharov, L. Zhang, et al., First results of lithium experiments on EAST and HT-7, J. Nucl. Mater. 415 (1) (2011) S1062–S1066.
[13] J.S. Hu, G.Z. Zuo, J.G. Li, N.C. Luo, L.E. Zakharov, L. Zhang, et al., Investigation of lithium as plasma facing materials on HT-7, Fusion Eng. Des. 85 (6) (2010) 930–934.
[14] Z. Sun, J.S. Hu, G.Z. Zuo, J. Ren, J.G. Li, L.E. Zakharov, et al., Development of and experiments with liquid lithium limiters on HT-7, J. Nucl. Mater. 438 (2013) S899–S904.
[15] J. Ren, J.S. Hu, G.Z. Zuo, Z. Sun, J.G. Li, D.N. Ruzic, et al., First results of flowing liquid lithium limiter in HT-7, Phys. Scr. T159 (2014) 5.
[16] D.N. Ruzic, W. Xu, D. Andruczyk, M.A. Jaworski, Lithium–metal infused trenches (LiMIT) for heat removal in fusion devices, Nucl. Fusion 51 (10) (2011), 102002 (4pp).
[17] G.Z. Zuo, J. Ren, J.S. Hu, Z. Sun, Q.X. Yang, J.G. Li, et al., Liquid lithium surface control and its effect on plasma performance in the HT-7 tokamak, Fusion Eng. Des. 89 (12) (2014) 2845–2852.
[18] L.E. Zakharov, W. Blanchard, R. Kaita, H. Kugel, R. Majeski, J. Timberlake, Low recycling regime in ITER and the LiWall concept for its divertor, J. Nucl. Mater. 363 (2007) 453–457.
[19] H.Y. Wang, J.S. Hu, X. Gao, B. Cao, J. Li, B. Pegourie, et al., Influence of Li and B coatings of metal walls on deuterium retention and plasma confinement in HT-7, Nucl. Fusion 52 (10) (2012), 103002 (6pp).