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Experimental Validation of Tritium Recovery System from Liquid PbLi by Vacuum Sieve Tray Concept

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BACKGROUND

Based on successful Proof of Principle, Vacuum Sieve Tray (VST)[1] as shown in Fig. 1, development is in technical demonstration / maturity phase.
Tritium Extraction Efficiency (TEE) from liquid PbLi is a significant function of a liquid breeding blanket (LBB). Design review of ITER Test Blanket Module (TBM) program, categorized VST tritium extraction method [2] as still less technically matured.
Probable issues are
a) TEE degradation by the dense distribution of multiple nozzle arrays.
b) Unstable performance in continuous operation and risk of degradation in long term operation.

- Purpose of this study -

To identify dynamic characteristics and reliability of VST under multiple droplets conditions.

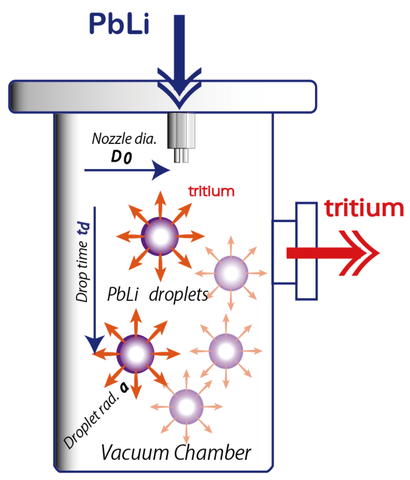
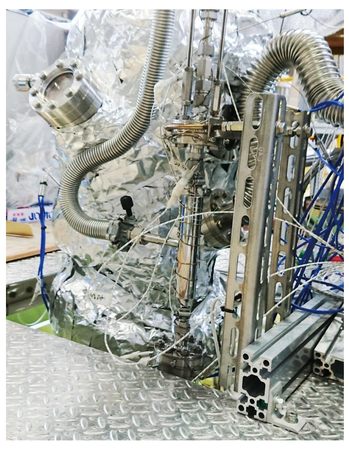


Fig. 1. A schematic of VST
Tritium is efficiently recovered from liquid PbLi droplets while falling in a vacuum. The internal dispersion caused by the spherical oscillation contributes the enhancement.

[1] F. Okino et al., Feasibility analysis of vacuum sieve tray for tritium extraction in the HCLL test blanket system, Fus. Eng. Des. 111 (2016) 1748-1753.
[2] I. Ricapito et al., Tritium technologies and transport modelling: main outcomes from the European TBM Project, Fus. Eng. Des. (2018) https://dosi.org/10.1016/j.fusengdes.2018.01.023.

CURRENT STATUS

1) Setup fabrication. As shown in Fig. 2-a-1, Fig. 2-a-2 and Fig. 2-a-3.
The VST setup was integrated into the liquid metal test loop Oroshhi-2[3] at the National Institute for Fusion Science (NIFS). By the waves of Laboratory shut-down, the schedules were extremely delayed. Function checks of the D_2 dissolution into PbLi and permeation through concentration monitor are still underway.
Hereafter, obtained results of the basic function checks are reported.



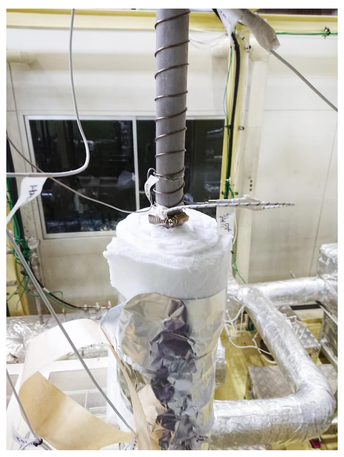


Fig. 2-a-1 (Left). The concentration monitor Before (CMb).
Permeated D2 gas through the monitor wall is conducted to the QMS.
Fig. 2-a-2 (Right) The D2 dissolving tube (DD) which is made of a double tube system, D2 gas is filled inside tube. PbLi flows through the outer tube. Heat shield is half removed for photograph.

Fig. 2-a-3. VST chamber.
From the top, D2 rich PbLi flows into the VST and turns into droplets through the nozzle which is located at the top of VST chamber. Heat shield is fully removed for photograph.

2) D_2 concentration monitor.
As shown in Fig. 2-b-1, A schematic of the D_2 concentration monitor and basic dimension is depicted. The concentration of dissolved D_2 in PbLi is measured using the permeation mass flow through a concentration monitor wall.
As a monitor wall material, the α (Alfa) iron (Fa) is preferred due to its high permeability and machinability. However, the material strength at high temperature (375 ℃ to 450 ℃) is not reported. STKM-11A JIS G3445 (Fs), low carbon engineering purpose iron STKM-11A (Fs) C<0.12 %, Si<0.35%, Mn<0.6%, P<0.04%, S< 0.04%, is applied due to the high temperature durability and commercial feasibility.
A comparison of the D_2 permeation between the Fa and Fs tube is shown in Fig. 2-b-2. A ratio of obtained permeability was Fs / Fa = 0.38, which is not equivalent but operable as a permeation monitor material.

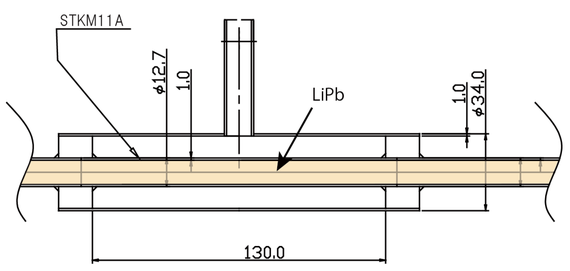


Fig. 2-b-1. A schematic of the D2 concentration monitor.

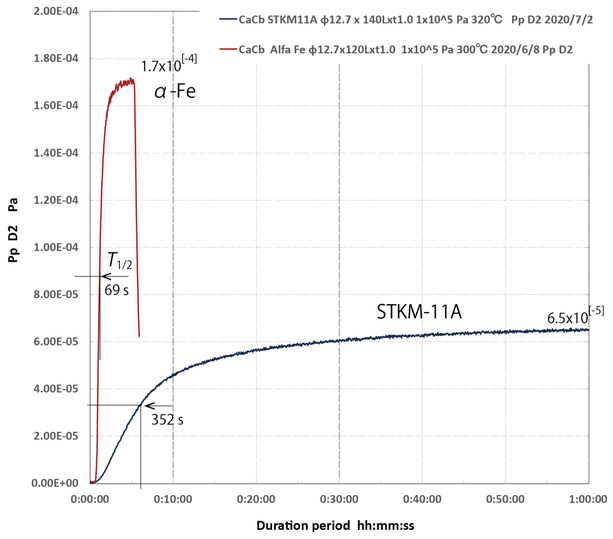


Fig. 2-b-2. A plots of the D2 permeation as a function of time.
Results of material Fa and Fs are plotted on a shame chart.
T=300℃ PD2=1×105 Pa, tube thickness 1mm. Vertical axis is arbitrary scale not calibrated, only relative comparison is effective.
Alfa iron (Fa) Fe>99.9%

[3] A. Sagara et al., Fus. Sci & Tech. 68 (2015) 303-307.

VERIFICATION CAMPAIGN PROCEDURES

1) Experimental setup.
A schematic diagram of the experimental setup is shown in Fig. 3-a.

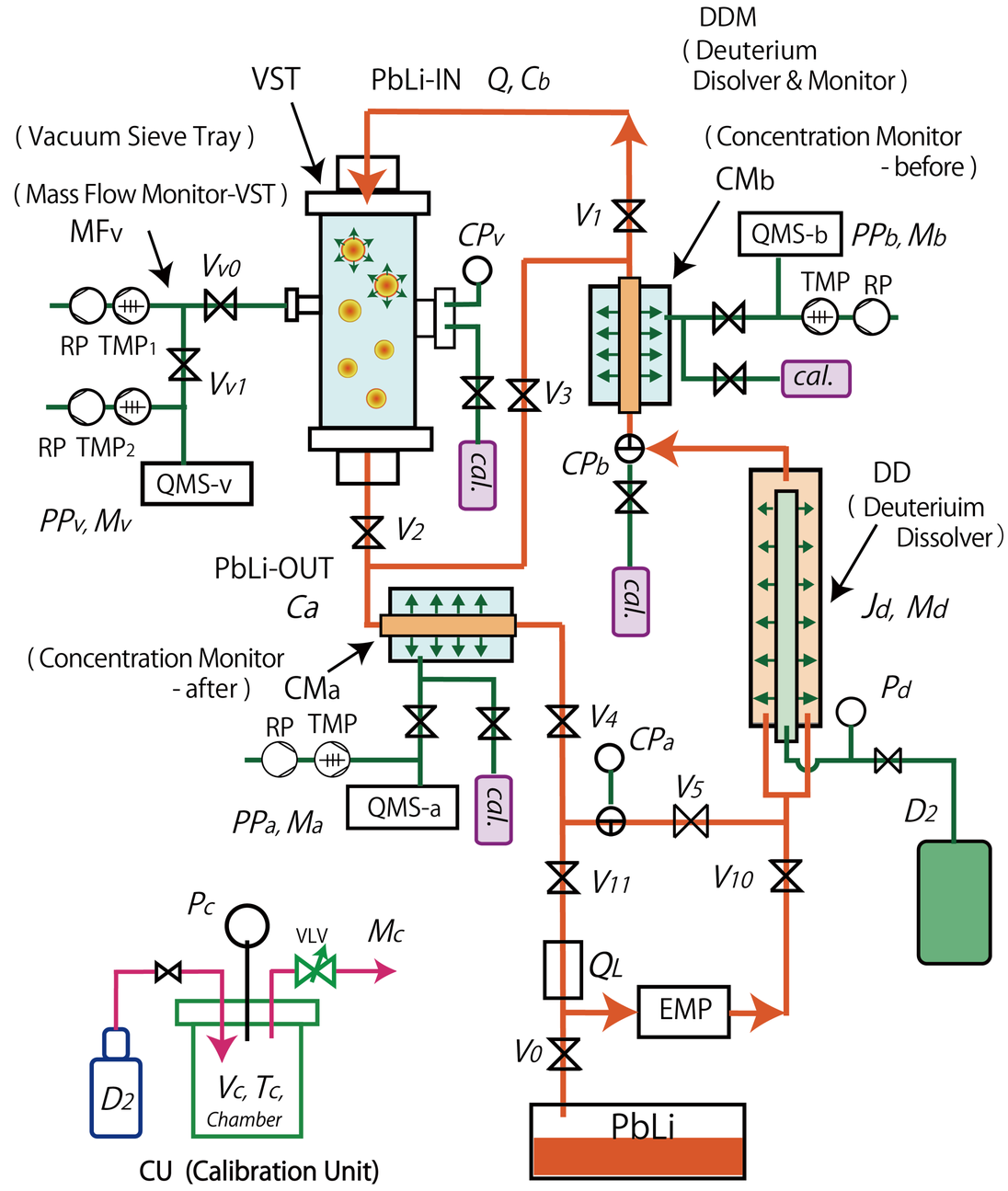


Fig. 3-a. A schematic of VST experimental setup.
Setup is consisted of a VST chamber which includes a droplet formation nozzle, a VST mass flow monitoring unit (MFv), a deuterium (D2) gas dissolution unit (DD), an electromagnetic pump (EMP), two concentration monitoring units (CMa, CMb), and vacuum pumping units. D2 is dissolved by permeation through an iron tube wall and is circulated by EMP. Liquid PbLi is turned into droplets by nozzles in VST, and while falling in a vacuum chamber, the dissolved D2 is recombined and released into a vacuum. The experimental temperature is between 375 ℃ and 450 ℃. Liquid PbLi nozzle flow velocity is between 1.5 ms^{-1} and 3.0 m s^{-1}.
A concentration of dissolved D2 in PbLi is measured as the permeation* through a monitor wall at CMb and CMa. A calibration unit (CU) is deployed to convert QMS reading of D2 partial pressure in Ampere into the mass flow rate. * The flow rate of PbLi is between 0.5 and 1.5 litter per minutes, the velocity effects to the permeation is neglected.

2) Obtained results.
As shown in Fig. 3-b, D_2 concentration dissolved in PbLi, is successfully monitored at CMb and CMa.
3) Discussions.
The permeated D_2 mass flow *Mb* and *Ma* are one order of magnitude less than those of pre-estimated values.
Probable causes are so far predicted as
① D_2 Leak in a PbLi flow loop
② Incorrect analysis model
③ Sieverts' constants not appropriate.

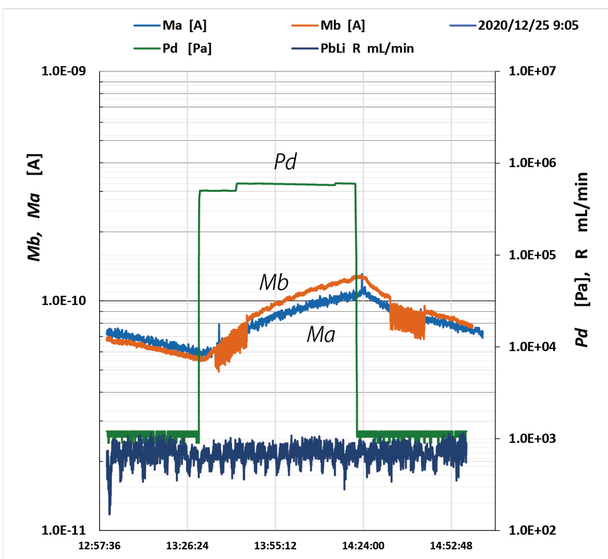


Fig. 3-b. A plots of Mb, Ma, the permeated D2 mass flow as a function of time at CMb and CMa.
Pd, the dissolved D2 gas pressure at DD, and R, the PbLi flow rate, are also plotted on a same chart. By the Pd valve open, Mb and Ma increase. By a shut down of Pd, Mb and Ma also decrease.
The left side vertical scale is the QMS D2 partial gas current, scale is arbitrary and not yet calibrated. A comparison between Ma and Mb has no meaning.

CONCLUSION

1) The VST technology for tritium extraction from PbLi is demonstrated in the Oroshhi-2 loop at an engineering scale.
2) Following demonstration campaigns have started.
Mass balance verification to ensure consistency with theory.
TEE measurements to verify multiple nozzle effects.
24h reliable operation to demonstrate VST engineering TRL.

ACKNOWLEDGEMENTS / REFERENCES

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