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Low tritium partial pressure permeation system for mass transport measurement in lead lithium eutectic

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HIGHLIGHTS

- New low tritium partial pressure permeation system for mass transfer measurements.
- Replaceable permeation cell for studies on metal, molten metal, and salt samples.
- LLE composition: 85.04 mol% Pb and 14.90 mol% Li with traces of Bi, Sn, and Zn.
- Tritium permeation has been measured in α-Fe and liquid lead lithium eutectic.
- Permeation data spans transition between diffusion and surface limited regimes.

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ABSTRACT

This paper describes a new experimental system designed to investigate tritium mass transfer properties in materials important to fusion technology. Experimental activities were carried out at the Safety and Tritium Applied Research (STAR) facility located at the Idaho National Laboratory (INL). The tritium permeation measurement system was developed as part of the Japan/US TITAN collaboration to investigate tritium mass transfer properties in liquid lead lithium eutectic (LLE) alloy. The experimental system is configured to measure tritium mass transfer properties at low tritium partial pressures. Initial tritium permeation scoping tests were conducted on a 1 mm thick α-Fe plate to determine operating parameters and to validate the experimental technique. A second series of permeation tests was then conducted with the α-Fe plate covered with an approximately 8.5 mm layer of liquid lead lithium eutectic alloy (α-Fe/LLE). We present preliminary tritium permeation data for α-Fe and α-Fe/LLE at temperatures between 400 and 600 °C and at tritium partial pressures between 1.7E − 03 and 2.5 Pa in helium. Preliminary results for the α-Fe plate and α-Fe/LLE indicate that the data spans a transition region between the diffusion-limited regime and the surface-limited regime. Additional data is required to determine the existence and range of a surface-limited regime.

1. Introduction

Fusion power promises to provide electricity generation with outstanding safety and environmental performance. Safety plays a crucial role in fusion material selection since tritium behavior in materials determines two key safety evaluation source terms: in-vessel inventory source term and ex-vessel release term, which are used in reactor safety assessments for licensing fusion facilities. Tritium permeation through materials at elevated temperature during long pulse operation is a significant safety concern, and better understanding of tritium behavior in blanket materials is required to build an effective and safe blanket system. Liquid lead lithium eutectic (LLE) alloy has been selected for the helium-cooled lead lithium (HCLL) Test Blanket Module (TBM) in ITER and the dual coolant lead lithium (DCLL) concept, which is the leading blanket system in the US Fusion Nuclear Science Facility and in future fusion demonstration (DEMO) reactor designs. The tritium partial pressure in these blanket systems is expected to be less than 100 Pa, but there is no experimental database for LLE at low tritium partial pressures.

Abbreviations: LLE, lead lithium eutectic.

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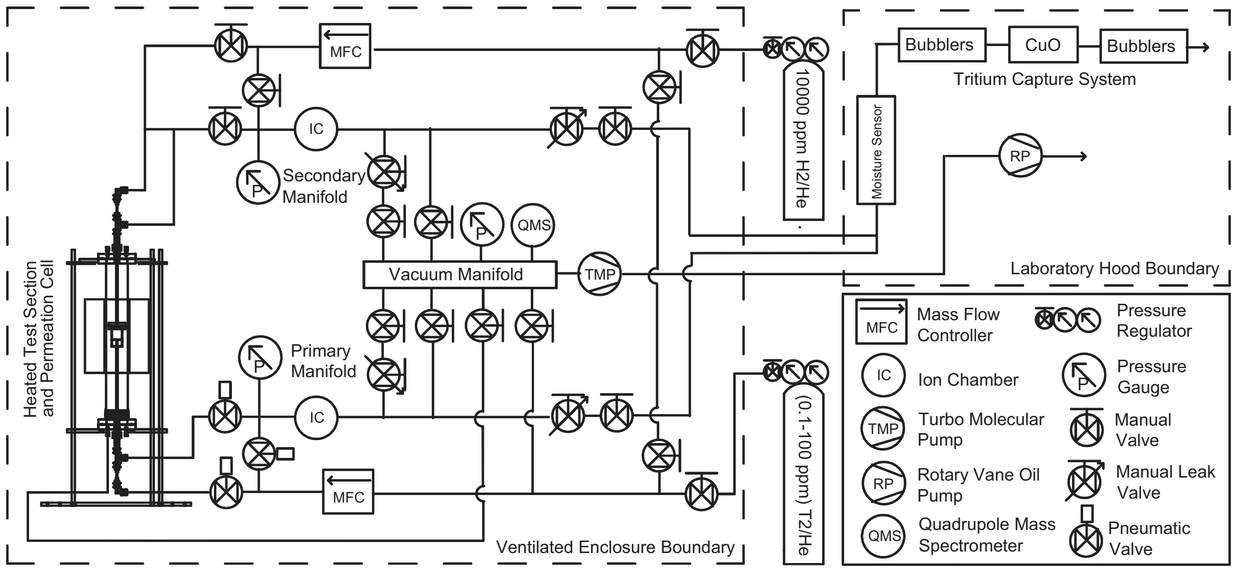

Fig. 1. Simplified schematic of the tritium permeation measurement system.

One task of the Japan/US TITAN collaboration focused on investigating the tritium mass transport properties (permeability, diffusivity, and solubility) in liquid LLE at low tritium partial pressures. To accomplish this task a new tritium permeation measurement system was developed at the Safety and Tritium Applied Research (STAR) facility located at the Idaho National Laboratory (INL). The system is similar to a hydrogen/deuterium permeation measurement system developed at Kyushu University and also incorporates lessons learned from previous tritium permeation experiments conducted at the STAR facility [1]. The Kyushu University hydrogen/deuterium permeation system was used to obtain the diffusion limited mass transport properties of hydrogen and deuterium in LLE at partial pressures ranging from 10^2 to 10^5 Pa [2,3]. The STAR facility tritium permeation measurement system compliments the Kyushu University system by investigating the mass transport properties of tritium in LLE at low tritium partial pressures where surface-limited permeation is known to occur in metals.

The tritium permeation measurement system, experimental method, and preliminary permeation data for α-Fe and α-Fe/LLE at low tritium partial pressures (<2.5 Pa) are hereafter presented and discussed.

2. Experimental system

The tritium permeation measurement system is housed in a ventilated enclosure and laboratory hood. Fig. 1 provides a simplified schematic of the experimental system. The primary components of the system include the LLE permeation cell, two independent gas manifolds, a tritium capture system, and a National Instruments (NI) LabVIEW based control and data acquisition system. A brief description of the system's primary components follows.

The LLE permeation cell is shown in Fig. 2. The cell is 4.1 cm in diameter and constructed of 304 stainless steel. A 1 mm thick (13.0 cm^2) α-Fe plate separates the cell into two chambers and also forms the permeation interface separating the primary and secondary gas manifolds. An evacuated quartz tube surrounds the permeation cell preventing tritium permeation from the primary to secondary chamber via the permeation cell walls. A tube furnace maintains the permeation cell at uniform temperature ranging between 300 and 600 °C and adjustable flow cold guns positioned directly above and below the tube furnace minimize the temperature gradient across the permeation cell. For the LLE experiments a 101.1 g PbLi sample was melted on the α-Fe plate creating a liquid LLE layer with a calculated thickness from 8.2 mm at 300 °C to 8.7 mm at 600 °C based upon the density measurement and a surface area of 13 cm^2 [4]. The permeation cell is replaceable to accommodate tritium permeation studies on metal, molten metal and salt samples.

Tritium test gas mixtures flow through the primary manifold and bottom chamber of the permeation cell. A 0 to 100 sccm mass flow controller, pressure sensor, and a leak valve are used to establish tritium test gas flow rates and pressures. Tritium concentrations in the primary manifold are measured with a 10 cm^3 Tyne ion chamber with a detection range of with 10^{-3} to 10^6 Ci/m^3.

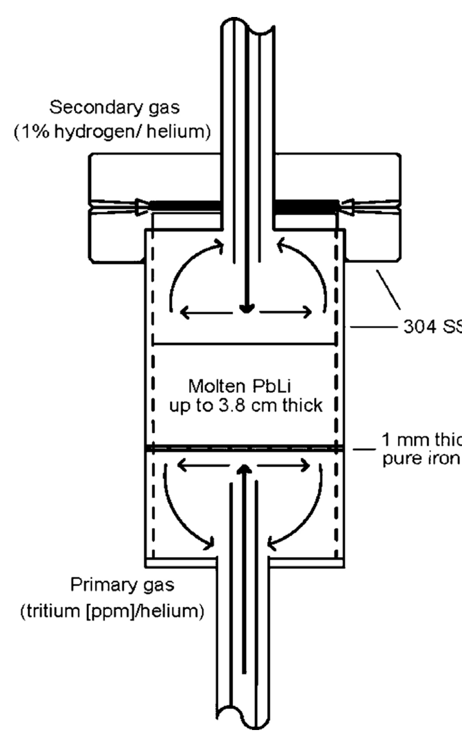

Fig. 2. Diagram of LLE permeation cell.