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Temperature dependence of the rate constant of hydrogen isotope interactions with a lithium capillary-porous system under reactor irradiation

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HIGHLIGHTS

- The experiments with Li CPS sample were carried out at reactor IVG-1.M.
- The gas absorption technique was used to study hydrogen isotope interaction with lithium CPS.
- The temperature dependence of constants of interaction rate was obtained for various power rates of the reactor.
- Determination of the activation energies, and pre-exponents of Arrhenius dependence.
- The effect of increase of the rate constant under reaction irradiation.

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ABSTRACT

Experiments with a sample of a lithium capillary-porous system (CPS) were performed at the reactor IVG-1.M of the Institute of Atomic Energy NNC RK to study the effects of neutron irradiation on the parameters of hydrogen isotope interactions with a lithium CPS. The absorption technique was used during the experiments, and this technique allowed the temperature dependences of the hydrogen isotope interaction rate constants with the lithium CPS to be obtained under various reactor powers. The obtained dependencies were used to determine the main interaction parameters: the activation energies and the pre-exponents of the Arrhenius dependence of the hydrogen interaction rate constants with lithium and the lithium CPS. An increase of the hydrogen isotope interaction rate with the lithium CPS was observed under reactor irradiation.

1. Introduction

Kazakhstan specialists, in cooperation with Russian scientists, have recently created a lithium module of the receiving divertor device for Kazakhstani Material Testing Tokamak KTM [1,2]. One of the important and unique features of the tokamak's lithium systems is the sorption abilities of these systems against all the gases, which allows good vacuum conditions to be created and the working gas in the fusion reactor (FR) chamber to be recycled. Another important process, to which particular attention must be paid while designing and operating the FR with lithium components, is the tritium accumulation and release in lithium under neutron irradiation. The advantages of a lithium CPS as a plasma facing material has been experimentally confirmed with lithium targets in modeling conditions at the SPRUT electron beam facility, on QSPU and MC-200-UG plasma accelerators and in a "plasma focus" facility [3].

The main goal of our work is to study the processes of accumulation and release of hydrogen isotopes (tritium) from a lithium CPS under neutron irradiation for the future implementation of lithium technology into fusion reactors.

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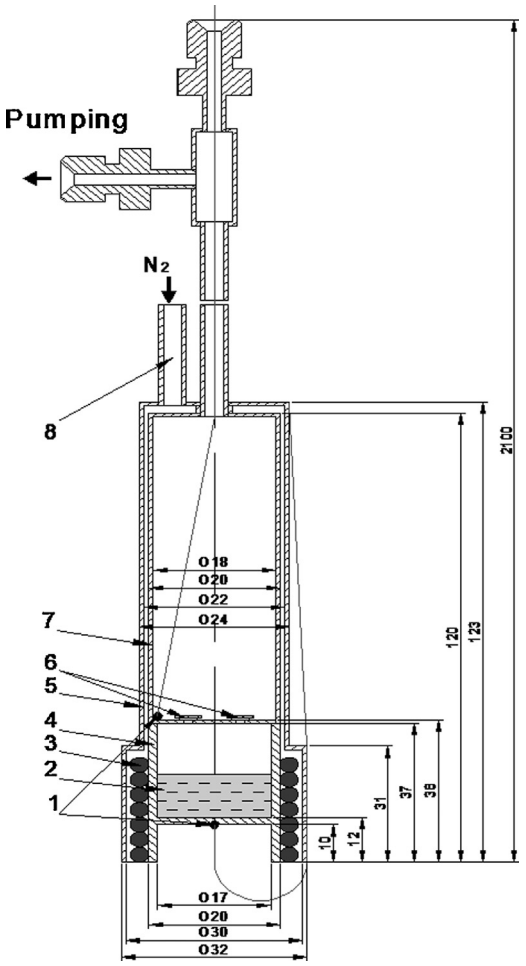

Fig. 1. Scheme of ampoule device with liquid Li: 1 – thermocouples, 2 – liquid Li, 3 – heater (with coatings 12X18H10T Ø 4 mm), 4 – ampoule body (cooper), 5 – cooling system boot (12Cr18Ni10Ti), 6 – reflecting screen, 7 – ampoule body (12X18H10T), and 8 – nitrogen supply tube.

2. Samples preparation and experimental procedure

2.1. Manufacturing and preliminary preparation of investigated samples

The technology used to manufacture and prepare the samples was described in [4,5]. The preliminary preparations for the experiments included pumping out (10^{-5} Pa) the device with the CPS and high-temperature degassing for 10 h while continuously pumping out. The CPS was then filled with lithium, and the sample was placed in the reactor ampoule device, which was pumped out to a pressure of 10^{-4} Pa.

Two reactor ampoule devices have been developed and manufactured for the experiments with liquid lithium under conditions of reactor irradiation. The scheme of such reactor ampoule devices is given in Fig. 1. It includes:

(1) an active cell with thermocouples, a heater and the investigated samples (in one of ampoules, a sample of naturally enriched lithium was used; for the other ampoule, a sample of lithium capillary-porous system (CPS) was used);
(2) a nitrogen cooling system.

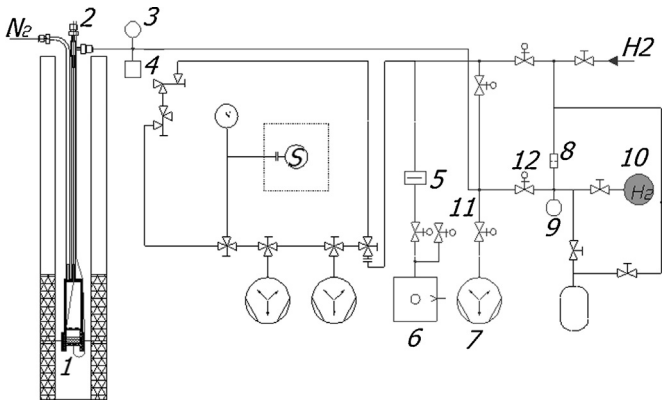

Fig. 2. LIANA experimental reactor test bench: 1 – ampul device, 2 – thermocouples 3 and 4 – pressure gauges, 5 – nitrogen trap, 6 – preevacuation pump, 7 – ion pump, 8 – Pd–Ag filter, 9 – mass-spectrometer, 10 – hydrogen capacity; 11 and 12 – vacuum valves.

2.2. Experimental technique

The experiments with lithium and lithium CPS samples were performed at the IVG-1.M reactor of the Institute of Atomic Energy NNC RK. The reactor ampoule device with a sample was installed into the LIANA test bench (Fig. 2) and loaded into the reactor channel. (The scheme of the ampoule position is shown in Fig. 2.)

The experiments were performed by using a gas absorption technique. The experimental procedures for both the lithium and lithium CPS samples were similar: after installing an ampoule into the channel, the ampoule with the sample was pumped out to 10^{-4} Pa. The sample was heated rapidly up to 773 K (for the efficient dissolution of impurities on the surface), and the temperature of the studied sample was then set at a specified value. Afterward, the chamber was filled with a given quantity of gas, and the sample was saturated from the gas phase under a constant temperature. Changes in the hydrogen pressure in the ampoule volume above the sample were then measured. After obtaining the dependence of the hydrogen pressure changes in the ampoule for the given temperature, the temperature of the sample was changed. After the completion of the pre-reactor experiments on the hydrogen absorption for various temperatures, the reactor was powered (the period between the pre-reactor and post-reactor experiments was as short as possible), and the reactor experiments on the hydrogen absorption by the sample were performed. Immediately after the reactor experiments were completed, a series of post-reactor experiments was performed. After recording the pressure data in the ampoule with the sample for the complete range of studied temperatures, the ampoule was pumped out with the ion pump, and a new cycle of tests started. Out-of-pile, in-pile and post-reactor experiments were performed in temperature ranges from 473 to 623 K. The residual pressure in the measurement circuit was 10^{-4} to 10^{-6} Pa. The reactor power was 1.3 and 6 MW.

3. Results of the experiments

3.1. Experiment with lithium

The experiments allowed the dependences of the changes in the hydrogen pressure over liquid lithium under temperatures from 473 to 623 K to be obtained. For these temperatures, we could clearly see the influence of the reactor irradiation on the hydrogen interaction rates with liquid lithium. This influence resulted in increased hydrogen absorption by the lithium under reactor irradiation (see Fig. 3). The experimental results showed that an increase