Isotope effects in the interaction of hydrogen with low-activation steels

Shishkova Tatyana Alexandrovna

Relevance of the Research Topic. Currently, work aimed at the practical implementation of thermonuclear fusion is based on the use of a reaction on a mixture of heavy isotopes of hydrogen — deuterium and tritium. During operation of a fusion or hybrid ("fusion—fission") reactor, hydrogen isotopes will interact with the walls of the vacuum vessel in which the fusion reaction will take place. The amount of tritium trapped in the reactor's structural and plasma-facing materials, as well as the tritium flows penetrating through them, are among the main factors affecting the safety and economics of a fusion reactor. In this regard, the hydrogen isotopes transport parameters and retention are important criteria when choosing materials for the vacuum vessel of a fusion facility.

Austenitic stainless steel type 316L is used as the structural material of the vacuum vessel of the fusion reactor ITER under construction. Low-activation ferritic martensitic steels are offered for the projected fusion reactors DEMO. Nickel-free austenitic steels can become an alternative to high-activation austenitic and low-activation ferritic martensitic steels. Low-activation ferritic martensitic steel EK-181 and chromium-manganese low-activation austenitic steel Fe-11Cr-23Mn-W-V-Ti (hereinafter — LAS) have been developed in the Russian Federation. Russian steels EK-181 and LAS can be considered for use in fusion facilities. The parameters of hydrogen isotope transport in low-activation austenitic chromium-manganese steels have not been studied before.

In the framework of the study of the retention of hydrogen isotopes in structural and plasma—facing materials of a fusion reactor, one of the important directions is the search for effective methods for the tritium removal. In order for the retention of tritium in the vacuum vessel not to exceed the set limit during operation of the fusion facility, periodic cleaning of the vacuum vessel materials from tritium is necessary. The maximum allowable amount of tritium contained in the vacuum vessel during operation of the fusion plant will be limited by safety standards (~ 1 kg

for the ITER project). For the tritium removal of the vacuum vessel, including in the ITER project, methods based on thermal desorption and isotope exchange are being considered. The task of extracting tritium from materials is also relevant in the context of replacing reactor elements or preparing them for final disposal.

Due to the complexity of work with tritium, experimental work on determining the hydrogen isotopes transport parameters in materials and the effectiveness of tritium removal methods for materials is more often carried out with protium and deuterium. The results obtained are used to evaluate the characteristics of the interaction of tritium with materials.

The aim of the work is to obtain a set of physico-chemical data on the interaction of hydrogen isotopes with domestic low-activation steels EK-181 and LAS, necessary to assess the possibility of using these steels as structural materials for fusion reactor.

Objectives of the work:

1. To compare the efficiency of deuterium extraction from EK-181 steel by hydrogen isotope exchange and thermal desorption;

2. To determine the parameters of the interaction of hydrogen isotopes (diffusivity, permeability and solubility of deuterium and protium) with low-activation austenitic chromium-manganese steel.

Scientific Novelty:

1. The isotope substitution of deuterium with protium in EK-181 steel by plasma irradiation and gas exposure was investigated for the first time. It is shown that at a temperature of 473 K, isotope substitution with protium is a more effective method of removing deuterium from EK-181 steel than heating in vacuum.

2. The interaction of hydrogen isotopes with low-activation austenitic chromium-manganese steel (LAS) has been studied for the first time. The values of the diffusivity, permeability, and solubility of protium and deuterium in low-activation austenitic steel (LAS) in the temperature range 468-653 K.

3. It has been established for the first time that hydrogen isotope fluxes penetrating through low-activation austenitic steel (LAS) significantly depend on

the condition of the surfaces. The application of Pd coatings with a thickness of 0.1 μm after ion purification of the membrane surfaces from LAS leads to a tenfold increase in the penetrating deuterium flux at temperatures of 583 K and 623 K.

Theoretical and Practical Significance. The obtained temperature dependences of the diffusivity and permeability of protium and deuterium through low-activation austenitic chromium-manganese steel make it possible to determine the fluxes of hydrogen isotopes through this material in fusion facilities and evaluate the prospects of LAS as a structural material.

It has been shown that hydrogen isotope exchange by plasma irradiation is an effective method for removing deuterium from EK-181 steel. The results of studies on the removal of deuterium from EK-181 steel by isotope exchange and thermal desorption methods can be used to select a method for tritium removal from this material in fusion facilities.

Statements to be defended:

1. The effect of the heating temperature in the range of 373-623 K on the efficiency of thermal desorption of deuterium from steel EK-181. The heating time at a temperature of 473 K, depending on the thickness of the sample, is necessary to achieve the efficiency of the thermal desorption process ≥ 98%.

2. The effect of protium pressure on the efficiency of deuterium substitution in steel EK-181 when held in H_2 gas at a temperature of 473 K.

3. Comparison of the efficiencies of thermal desorption and isotope exchange processes by plasma irradiation and gas exposure as methods for removing deuterium from EK-181 steel.

4. The obtained diffusivity, permeability and solubility of protium and deuterium in LAS at temperatures 468-653 K and pressures on the inlet side of the LAS membrane $10^3 – 5 \times 10^4$ Pa.