PERMEABILITY OF HYDROGEN THROUGH METALS: THE THEORY AND EXPERIMENT

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Introduction

The study of hydrogen isotopes permeability parameters represents the large practical interest both for a science and for a prediction of behaviour of materials in installations such as ITER.

However at experimental reception and data processing on permeability of hydrogen there are very many phenomena that are difficultly giving in to an explanation. So, for example, is shown, that at study of dependence of permeability of metals for considered gases from pressure P_0 on the input side of membranes (output side in vacuum P_{out}=0) the deviations from theoretical dependence of a flow offered Richardson with the co-authors are observed [1]:

$$J_m = \frac{F\eta}{\delta}\cdot\left(\sqrt{P_0} - \sqrt{P_{out}}\right), \qquad (1)$$

where J_m - gas current through a membrane, P_0 and P_{out} - pressure of hydrogen on input and output the sides of a membrane, accordingly, η=DS - permeability of a material for the given kind of gas at P_0 = 1 atm and Pout = 0; F - area of a membrane, S - solubility of gas in metal at pressure of gas equal 1 atm; D - diffusivity of gas in metal; δ - thickness of a membrane.

The deviations in dependence of meanings of a flow J_{mes} from specified in the equation (1) dependences from P_0 and δ are especially appreciable at low pressures of hydrogen on the input side of a membrane. For the description of these deviations in the literature the various empirical formulas are resulted [2], together with phenomenological description of these phenomena. However of substantial physical process, resulting in to similar deviations, on our sight, till now is not found.

In the present work the attempt is made to explain the most part of observed deviations in J_{mes} from J_m to that the vacuum pipelines, and pipelines delivering gas to an investigated material, are as a matter of fact gas membranes connected successively with investigated one.

The equation of a hydrogen flux through a membrane.

Let's consider measurement of permeability through a membrane, the gas to which is made at the left on a tube 1 and is removed on a tube 2 on the right (see fig. 1). Let on an input in a tube 1 pressure of gas is equal P_0, on an input surface of a membrane the pressure is equal P_1, from the output side of a membrane the pressure is equal P_2 and on output of a tube 2 pressure equally P_{out} = 0. Let's assume, that the measurements are conducted in the study-state mode. Then the gas current will be in any section identical (see fig. 1), and is equal measured J_{mes}.

$$J_{mes} = J_1 = J_m = J_2. \qquad (2)$$

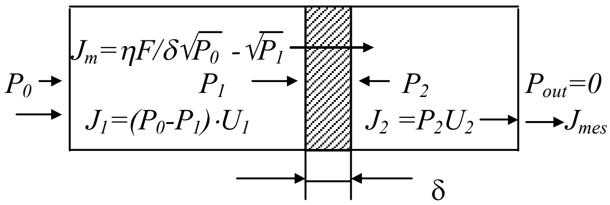

Fig. 1. The schema of definition of hydrogen permeability through a membrane, J_1, J_2 and J_m - gas currents through tubes 1 and 2 and membrane, accordingly, U_1, U_2 - conductivity of tubes 1 and 2.

From the equation (2) it is possible to receive connection between parameters of system: η, δ, P_0, U_1 and U_2

$$P_0 = AJ_{mes}^2 + BJ_{mes}^{3/2} + CJ_{mes}, \qquad (3)$$

where

$$A = \left(\frac{\delta}{\eta F}\right)^2, \quad B = \frac{2\delta}{\eta F\sqrt{U_2}}, \quad C = \frac{(U_1 + U_2)}{U_1\cdot U_2}.$$

From the equation (3) follows, that only in a case if $U_1 \to \infty$ and $U_2 \to \infty$ the measured J_{mes} corresponds to its true value, since in this case $A \to 0$ and $B \to 0$ and

$$J_{изм} \approx \frac{\eta F}{\delta}\sqrt{P_0}, \qquad (4)$$

according to the Richardson's equation [1].

Discussion of results

As an example of applicability of the deduced above equations to the analysis of the data on permeability we shall consider results of measurement of dependence of a hydrogen flux from pressure on the input side through niobium [3] (fig. 2a), and also dependence of a hydrogen flux at constant pressure P_0 from thickness of nickel membrane of (fig. 2b). From figures 2a and 2b it is visible, that neither in one case is not observed of linear dependence nor from a root from pressure (fig. 2a), from reciprocal thickness of a membrane (fig. 2b), that will not be considered to the Richardson's equation (1).

Processing the above-stated data on the equation (3) has shown, that for niobium $1/U_1$=0, $1/U_2 \neq 0$ and, hence, restriction of flux responsible for a nonlinear course of dependence in a fig. 2a, is carried out on the output side of a membrane, and for nickel (fig. 2b) $-1/U_2$=0 и $1/U_1 \neq 0$, i.e. the flux of hydrogen is limited on the input side of a membrane. The analysis of the equation (3) shows, that for niobium, in a case ($U_1 \to \infty$), the dependence (fig. 2a) owes to straight-line in coordinates:

$$\frac{\sqrt{P_0}}{J_{mes}} = f\left(\frac{1}{\sqrt{J_{mes}}}\right), \tag{4}$$

And for nickel at $U_2 \to \infty$ in coordinates:

$$\frac{P_0}{J_{mes}} = f(J_{mes}) . \tag{5}$$

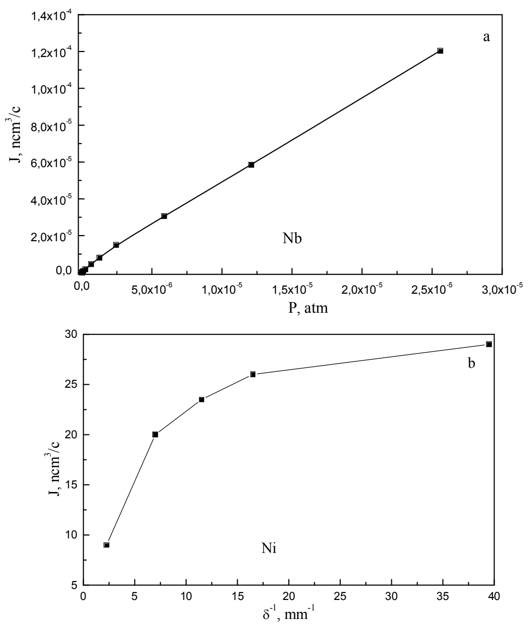

Fig. 2. Dependence of a hydrogen flow through Nb from pressure (a) and through Ni from thickness of a membrane (b) on the data [3] and [2], accordingly.

These dependences are given in a fig. 3a and 3b, from which one can see, that in both cases the linear ratios are carried out well enough.

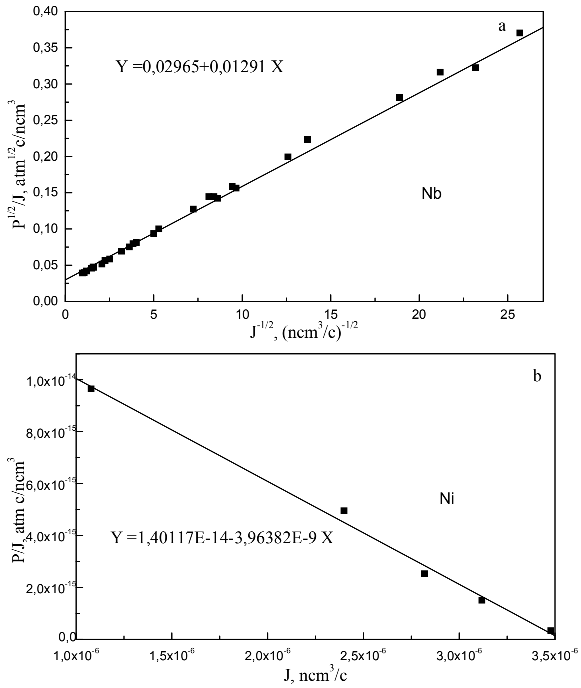

Fig. 3. Dependence of a hydrogen flow through Nb (a) and through Ni (b) in coordinates of the equations (4) and (5), accordingly.

Conclusions

The technique of definition of the side of a membrane (input or output), responsible for a deviation from the Richardson's law a is offered at measuring of permeability of hydrogen through metals and alloys.

References

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