NOTATION

V_1, V_2, gas volumes; R, radius of the channel; H, length of the channel; L, dimensionless channel length; ρ, radial coordinate; X, X', dimensionless radial coordinate; Z, longitudinal coordinate; Y, Y', dimensionless longitudinal coordinate; J, J_0, J_1, number flux densities; $d\sigma_1$, $d\sigma_2$, surface elements; α, probability that a molecule is absorbed in colliding with the wall; $\beta = 1 - \alpha$, probability that a molecule is diffusely reflected in colliding with the wall; W_p, W_r, W_a, probabilities of passage, return, and absorption; b, variational constant; q, ℓ, dimensionless parameters; L_{eff}, dimensionless effective penetration depth of the molecules in the channel; A, B, C, D, frequently used functions.

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EFFECT OF PERFORATION OF A RADIATION SCREEN ON PREEVACUATION OF EXTENDED CRYOGENIC SYSTEMS WITH HIGH-VACUUM THERMAL INSULATION

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UDC 533.5

Relations for determining the degree of perforation of the radiation screen as a function of the magnitude of gas evolution from the inner surfaces are obtained.

The traditional cryogenic system with high-vacuum thermal insulation usually consists of a vacuum chamber containing the object being cooled, surrounded by a radiation screen. The cooling process is preceded by preliminary evacuation of the vacuum volume. In those cases when the conductance of the evacuation channels in the chamber is quite high, the evacuation proceeds in the normal manner. In a number of cryogenic systems, however, the cross sections of the extended evacuation channels with a significant level of gas evolution, especially from the objects being cooled, are small. In this case large pressure drops (not only in the direction of evacuation) can occur in the chamber.

We shall study the process of preevacuation of such cryogenic systems for the model indicated in Fig. 1. In the calculations performed below it is assumed that gas evolution from the walls of the vacuum chamber and from the surface of the radiation screen is much weaker than gas evolution from the surface of the object being cooled and from the standard localized source at the far end of the chamber away from the pump.

These assumptions correspond to real cryogenic systems, where the walls of the chambers are usually made of materials with a low level of gas evolution. The object being cooled is itself often prepared with the use of polymers and the soldered and welded connections have large surfaces with a high level of gas evolution.

It should be noted that under real conditions it is virtually impossible to remove fluxes used in soldering from the surface and to remove different organic contaminants, which unavoidably remain after the preparation and assembly. Therefore, the magnitude of the gas evolution is determined not so much by the diffusion-desorption processes, occurring with molecules of gas dissolved in the bulk of the material or adsorbed on its surface, as by means of the saturated vapor pressure of different contaminants present on the object

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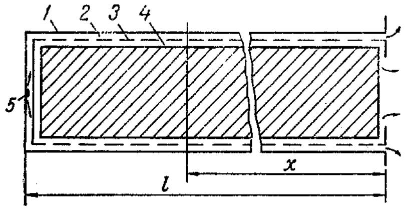

Fig. 1. Working model of an extended cryogenic system with high-vacuum thermal insulation: 1) wall of vacuum chamber; 2) radiation screen; 3) perforation of radiation screen; 4) surface of object being cooled; 5) localized source of gas evolution.

being cooled [1]. Taking into account the fact that the rate of preevacuation is determined completely by the conductance of the evacuation channels and is therefore low, it may be asserted with confidence that over a time of 10-20 h, which under real conditions is the time required for preevacuation from a pressure of 10^5-10^{-2} Pa, the magnitude of gas evolution from the surface of the object being cooled will remain constant and independent of the pressure [2]. All further calculations will be performed for the molecular regime. This is explained by the fact that evacuation from a pressure of 10^5 to a pressure of 1 Pa does not present any difficulties, even for evacuation channels with small cross sections. The main difficulty arises when the pressure is reduced from 1 to 10^{-2} Pa. In this pressure range, for evacuation cross sections with a standard diameter of $2\cdot10^{-2}$ m and less, $Pd \leq 0.02$ Pa·m [3], where $P = (P_1 + P_2)/2$ is the average pressure in the system and d is the standard diameter of the pipe line. This condition corresponds to the criterion of the molecular regime. In addition, in further calculations it is assumed that $d \ll \ell$.

The equation describing the pressure distribution in an extended system for the molecular regime has the form [2]

$$P_x - P_0 = \frac{q\left(lx - \frac{x^2}{2}\right)\Pi + Qx}{U_m l}. \tag{1}$$

Since in the molecular regime transfer of gas flows through the perforations in the radiation screen between channels occurs independently and does not alter the nature of the equations determining the pressure drop in extended systems, we write (1) for transfers between the screen and the chamber wall and the screen and the object being cooled

$$P_{x1} - P_0 = \frac{Q_1 x}{U_1 l} - \frac{\alpha Q_1 x}{U_1 l} + \frac{\alpha Q_2 x}{U_2 l} - \frac{\alpha Q_2 x^2}{2U_2 l^2}, \tag{2}$$

$$P_{x2} - P_0 = \frac{Q_2 x}{U_2 l} - \frac{\alpha Q_2 x}{U_2 l} - \frac{Q_2 x^2}{2U_2 l} + \frac{\alpha Q_1 x}{U_1 l} - \frac{\alpha Q_1 x^2}{2U_1 l^2}. \tag{3}$$

In Eq. (2) $\frac{Q_1 x}{U_1 l} - \alpha\frac{Q_1 x}{U_1 l}$ is the pressure drop owing to the gas load Q_1 taking into account the flow of part of the gas out of the volume between the chamber wall 1 and the screen 2 through the opening 3 in the volume between the screen 2 and the object being cooled 4, $\frac{\alpha Q_2 x}{U_2 l} - \frac{\alpha Q_2 x^2}{2U_2 l^2}$ is the pressure drop caused by the evolution of the gas from the surface 4 through the opening 3 into the volume between the screen 2 and the wall of the vacuum chamber 1.

In Eq. (3) $\frac{Q_2 x}{U_2 l} - \frac{\alpha Q_2 x}{U_2 l} - \frac{Q_2 x^2}{2U_2 l^2} + \frac{\alpha Q_2 x^2}{2U_2 l^2}$ is the pressure drop determined by the evolution of gas from the surface 4 taking into account the escape of part of the flux Q_2 from the volume between the object being cooled 4 and the screen 2 through the opening 3 into the volume between the screen 2 and the chamber wall 1; $\frac{\alpha Q_1 x}{U_1 l} - \frac{\alpha Q_1 x^2}{2U_1 l^2}$ is the pressure drop formed by part of the flux Q_1 from the volume between the chamber wall 1 and the screen 2 through the opening 3 into the volume between the screen 2 and the object being cooled 4.

From Eqs. (2) and (3) we obtain an equation describing the pressure drop in the transverse section at a distance x from the evacuation section:

$$\frac{\Delta P}{P_2}=\alpha\left[(1-P_{11})\left(\frac{2x}{l}-\frac{x^2}{2l^2}\right)-\frac{x^2}{2l^2}\right]-\frac{x^2}{2l^2}-\frac{x}{l}(1-P_{11}), \tag{4}$$

where $P_{11} = P_1/P_2$, $P_1 = Q_1/U_1$, $P_2 = Q_2/U_2$.

From Eq. (4) with $\alpha = 0$ ("nontransmitting" screen)

$$\frac{\Delta P_{\alpha=0}}{P_2}=\frac{x^2}{2l^2}-\frac{x}{l}(1-P_{11}). \tag{5}$$

Let us see under what conditions $\Delta P_{\alpha\neq 0} > \Delta P_{\alpha=0}$. The inequalities

$$\frac{\Delta P_{\alpha\neq 0}-\Delta P_{\alpha=0}}{P_2}=\alpha\left[(1-P_{11})\left(\frac{2x}{l}-\frac{x^2}{l^2}\right)-\frac{x^2}{2l^2}\right]>0 \tag{6}$$

imply that

$$\frac{x}{l}<\frac{4(1-P_{11})}{(2-P_{11})}\quad\text{and}\quad P_{11}<1-\frac{\frac{x}{l}}{\left(4-\frac{x}{l}\right)}.$$

Taking into account the fact that $x/\ell < 1$, we obtain on the sections of the chamber: on the first section $0 < x/\ell < 4(1 - P_{11})(2 - P_{11})$ for $P_{11} < 1$, and on the second section $1 > x/\ell > 4(1 - P_{11})/(2 - P_{11})$ for $P_{11} < 1$ and $\Delta P_{\alpha\neq 0} > \Delta P_{\alpha=0}$. In the case when $P_{11} > 1$, substituting the values of P_{11}, P_1, and P_2, the following conditions can be written down:

$$\frac{\Delta P_{\alpha\neq 0}-\Delta P_{\alpha=0}}{P_2}=\begin{cases}>0\;\left\{\dfrac{Q_1U_2}{Q_2U_1}<1,\quad 0<\dfrac{x}{l}<\dfrac{4(Q_2U_1-Q_1U_2)}{2Q_2U_1-Q_1U_2},\right.\\[2ex] <0\;\left\{\begin{array}{ll}\dfrac{Q_1U_2}{Q_2U_1}>1, & \dfrac{Q_1U_2}{Q_2U_1}<1,\\[1ex] 0<\dfrac{x}{l}<1, & \dfrac{4(Q_2U_1-Q_1U_2)}{2Q_2U_1-Q_1U_1}<\dfrac{x}{l}<1.\end{array}\right.\end{cases} \tag{7}$$

If $U_1 \approx U_2$, then (7) assumes the form

$$\frac{\Delta P_{\alpha\neq 0}-\Delta P_{\alpha=0}}{P_2}=\begin{cases}>0\;\left\{\begin{array}{l}Q_1<Q_2,\\ 0<\dfrac{x}{l}<\dfrac{4(Q_2-Q_1)}{2Q_2-Q_1},\end{array}\right.\\[3ex] <0\;\left\{\begin{array}{ll}Q_1>Q_2, & Q_1<Q_2,\\ 0<\dfrac{x}{l}<1, & \dfrac{4(Q_2-Q_1)}{2Q_2-Q_1}<\dfrac{x}{l}<1.\end{array}\right.\end{cases} \tag{8}$$

Equation (8) implies that for a strong localized source of gas evolution the screen must be made "nontransmitting," i.e., the conductance of the technological slits in the screen must be much lower than the conductance of the evacuation channels between the screen and the object being cooled. Under conditions of intense gas evolution from the surface of the object being cooled the far end of the screen and its walls must be "nontransmitting" right up to distances $x = \ell 4(Q_2 - Q_1)/(2Q_2 - Q_1)$ from the evacuation section, and at closer distances and right up to the input evacuation section the conductance through the screen must be high.

NOTATION

ℓ, length of the evacuation channels; U_1, conductance of the chamber-wall–screen channel; U_2, conductance of the screen-object channel; Q_1, intensity of the localized source of gas evolution; Q_2, intensity of gas evolution from the surface of the object being cooled; α, perforation factor of the screen $\alpha = S_a/S$, where S_a is the total area of the openings in the screen and S is the geometric area of the surface of the screen; P_x, pressure in the system at a distance x from the inlet; P_0, pressure in the input section; q, specific gas-evolution flux from the walls of the system; Π, perimeter of the transverse section; x, distance from the inlet to the section under study; Q, gas load at the far end; and U_m, conductance in the molecular regime.

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HEAT PIPE WITH COMBINED CAPILLARY-POROUS STRUCTURE

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The authors present results of an experimental investigation of the heat-transfer characteristics of low-temperature heat pipes with longitudinal capillary grooves coated with a layer of porous metal.

A topic of current interest is to increase the heat transfer in heat pipes, to increase their heat transmission capability. One way to solve this problem is to use capillary-porous structures of combined type, various forms of which were investigated in [1, 2].

In this paper for the first time we examine a heat pipe with a capillary-porous structure in the form of a combination of longitudinal grooves and a fine porous metal layer, deposited in a comparatively simple manner described in [3, 4]. Figure 1, taken with a microcamera, shows a section of an element of such a structure. The porous copper coating was deposited on the inner surface of a copper tube with 24 open longitudinal rectangular grooves of depth D = 0.46 mm and half width W = 0.37 mm, serving as a cathode in the process of cathodic deposition from solution. To avoid secondary effects associated with concentrated polarization, we used copper sulfate electrolyte with triatomic alcohol additive vigorously mixed by means of compressed air. The prepared specimens were washed with water and dried with hot air. The structure thus obtained is a porous skeleton, consisting of spherically shaped particles with a developed surface, having good bonding with the substrate. Its porosity is 45%, the mean pore size is about 140 μm, and here the dimensions of the particles increase as distance from the substrate increases. As can be seen from Fig. 1, the thickness of the porous skeleton varies over the fin surface and is greatest at the fin apex.

The freshly formed trap@ezoidal capillary grooves differ from basic rectanges by having greater depth and less width at the exit to the heat-pipe vapor channel. This must necessarily lead to an increase of the maximum power transmitted by such a heat pipe under conditions where mass forces oppose transport of liquid [5]. In addition, a possible result of depositing the porous layer is to reduce the thermal resistance of the evaporator by increasing the area of liquid evaporation and intensifying the boiling process.

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