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DETERMINATION OF EVAPORATION LOSS FROM HELIUM DEWAR VESSELS WITHOUT NITROGEN COOLING

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The author presents a method of calculation and nomograms for determining the evaporation loss of liquid helium from small Dewar vessels without nitrogen cooling.

The storage and transportation of liquid helium are fairly complex technical problems in view of its low boiling point (4. 2°K) and heat of evaporation (20. 6 kJ/kg).

Usually liquid helium is stored and transported in vessels with vacuum insulation and screen cooled by liquid nitrogen or liquid air [1, 2]. If the evaporating helium is used to cool the screen, then it is possible to design a helium vessel without nitrogen cooling [3]. Such a vessel is simpler to construct, lighter, and easier to handle.

It is convenient to cool the screen of a small vessel by sealing it to the neck of the vessel, through which the evaporating gas ascends. In this case the neck forms a sufficiently rigid suspension for the liquid helium container and the screen, while the heat flow through it from the hot end to the screen and container is practically zero, since it is removed by the rising stream of gas (Fig. 1a).

The liquid helium container 0 is surrounded by a copper screen 1, which is isolated by the multi-layered screen-vacuum thermal insulation from the outer shell 2. The screen is sealed to the neck of the vessel at a certain distance ab from the container. The entire space between the container and the outer shell is evacuated to a pressure not higher than 10^{-2} N/m^2.

Considering the heat balance of the individual elements of the vessel, we can write the following system of equations (Fig. 1a):

$$Q_{10} + Q_{ba} = mL;\ Q_{21} + Q_{cb} = Q_{10} + Q_1;$$
$$Q_{cb} + Q_1 = Q_{ba} + m\,\Delta i_{10}; \tag{1}$$

$$Q_{10} = A_0 E_{10}\,\sigma (T_1^4 - T_0^4);\ Q_{21} = (T_2 - T_1)/R; \tag{2}$$

$$L_{ab} = \frac{A_{mp}}{mc_p}\left[\alpha_1 (T_1 - T_0) + \left(\lambda_0 - Q_{ba}\frac{\alpha_1}{mc_p}\right)\ln\frac{Q_{ba} + mc_p (T_1 - T_0)}{Q_{ba}}\right], \tag{2'}$$

$$L_{cb} = \frac{A_{mp}}{mc_p}\left[\alpha_2 (T_2 - T_1) + \left(\lambda_1 - Q_{cb}\frac{\alpha_2}{mc_p}\right)\ln\frac{Q_{cb} + mc_p (T_2 - T_1)}{Q_{cb}}\right].$$

Equations (1) are, respectively, the heat balance equations for the liquid helium container, the screen, and the section ab of the neck, with the assumption that there is no radiative heat transfer from screen to neck. Equations (2) and (2') are the usual heat transfer equations, and are derived from an examination of the heat transfer over sections ab and bc for complete heat exchange between gas and tube, i. e., for equal gas and tube temperatures at any section, and for a linear temperature dependence of the thermal conductivity of the tube material [4].

Solution of the above system of equations may be simplified considerably by assuming $Q_{ba} = Q_{cb} = 0$, which is sufficiently accurate for large values of ba and cb.

The system then becomes

$$Q_{10} = mL;\ Q_{21} = Q_{10} + Q_1;\ Q_1 = m\,\Delta i_{10}; \tag{3}$$

$$Q_{10} = A_0 E_{10}\sigma (T_1^4 - T_0^4);\ Q_{21} = (T_2 - T_1)/R. \tag{4}$$

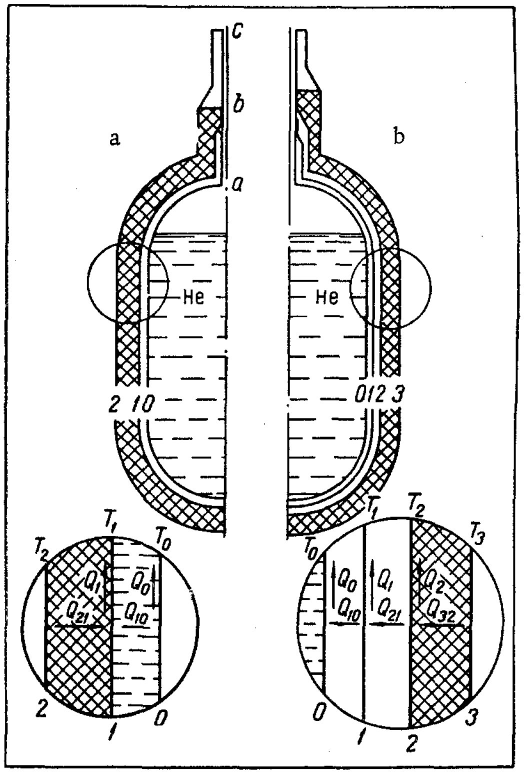

Fig. 1. Schematic of helium Dewar vessels without nitrogen cooling: a) with one screen; b) with two screens.

Making certain transformations, we have

$$m = (T_2 - T_1)/R(\Delta i_{10} + L), \quad (5)$$

$$m = \frac{A_0 E_{10} \sigma}{L} (T_1^4 - T_0^4). \quad (6)$$

In Fig. 2 equations (5) and (6) are given as families of curves at T_2 = 300°K.

To find the evaporation loss and the screen temperature the quantities $R = h/\lambda S_{av}$ and A_0E_{10} must be determined.

The ordinate and abscissa of the point of intersection of these curves give the evaporation loss (kg/sec) and the screen temperature T_1, °K, respectively.

In the Institute of Physical Problems of the Academy of Sciences USSR, two helium Dewar vessels without nitrogen cooling have been built. The insulation consists of alternate layers of fiberglass, thickness 120 μm, diameter of elementary fibers 6-7 μm, manufactured by the Sevansk Electrical Glass Insulation Plant, and soft aluminum foil, thickness 20 μm. The basic dimensions and certain design parameters of the vessels are given in the table.

Tests showed that the evaporation loss from a 25-liter vessel was 101 $\times 10^{-7}$ N/sec or 2.8% in 24 hours (with screen temperature 96°K), and from a 20-liter vessel 95 $\times 10^{-7}$ N/sec or 3.3% in 24 hours.

As may be seen from calculations and experiment, the evaporation losses from vessels of this type are somewhat high compared with vessels cooled with nitrogen.

In Fig. 2 the broken lines denote the boiling point of liquid nitrogen. All vessels with a screen temperature above the boiling point of liquid nitrogen will be less effective than vessels with nitrogen cooling.

Figure 2 also shows that only large vessels with good insulation can compare in respect of evaporation losses with vessels with nitrogen cooling.

Small quantities of liquid helium can conveniently be stored and transported in vessels without nitrogen cooling having two screens cooled by evaporating helium (Fig. 1b).

The beat balance equations for the different parts of a vessel without account for heat flow from the neck to the screens and container are as follows (Fig. 1b):

$$Q_{32} = Q_2 + Q_{21}; \; Q_{21} = Q_1 + Q_{10}; \; Q_{10} = mL; \quad (7)$$

$$Q_{10} = A_0 E_{10} \sigma (T_1^4 - T_0^4); \; Q_{21} = A_1 E_{21} \sigma (T_2^4 - T_1^4), \quad (8)$$

$$Q_{32} = (T_3 - T_2)/R;$$
$$Q_1 = m \Delta i_{10}; \; Q_2 = m \Delta i_{21}. \quad (9)$$

Transforming equations (7)-(9), we have

$$m = (T_3 - T_2)/R(\Delta i_{20} + L), \quad (10)$$

$$m = A_0 E_{10} \sigma (T_1^4 - T_0^4)/L, \quad (11)$$

$$T_2 = T_1 \left(\frac{A_0 E_{10}}{A_1 E_{21}} \left(1 + \frac{\Delta i_{10}}{L} \right) + 1 \right)^{1/4}. \quad (12)$$

Figure 2b gives a nomogram for designing two-scrren helium vessels without nitrogen cooling. The nomogram was constructed on the basis of equations (10)-(12) for different values of A_0E_{10} and R at T_3 = 300°K.

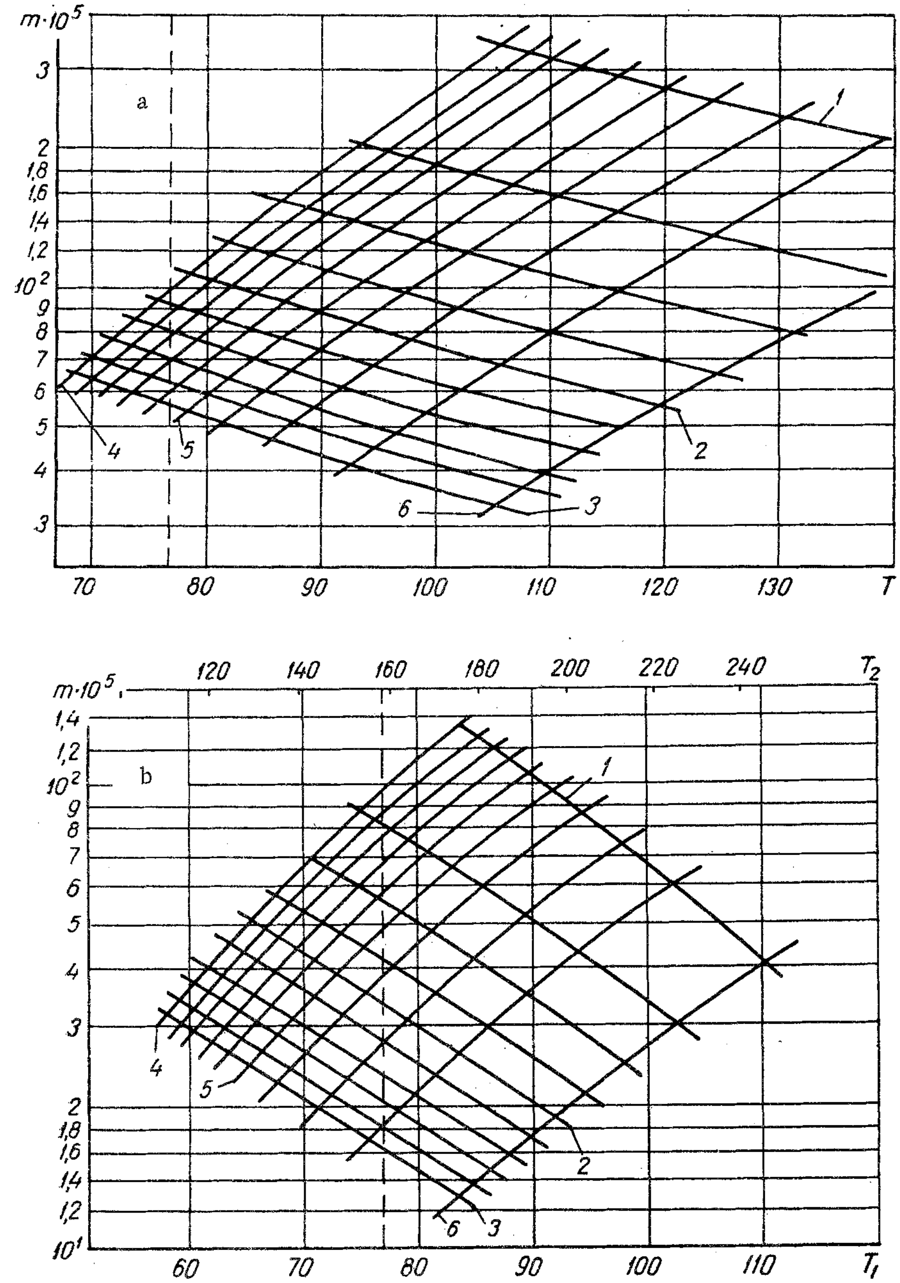

Fig. 2. Nomogram for the design of helium Dewar vessels without nitrogen cooling with one screen (a) and two screens (b): 1) $R = 0.1 \times 10^3$ deg/W: 2) 0.5×10^3; 3) 1.0×10^3; 4) $A_0E_{10} = 1 \times 10^{-2}$ m^2; 5) 0.5×10^{-2}; 6) 0.1×10^{-2}.

In constructing the nomogram it was assumed that in equation (12) $A_0E_{10} : A_1E_{21} = 0.85$; however, for variation of this ratio in the range from 0.75 to 0.95 the error in determining m is no more than 10%. Using the relations (5), (6), and (10)-(12), nomograms can be constructed for designing one- or two-screen hydrogen vessels without nitrogen cooling. However, in this case the temperature of the vapor-cooled screen will be significantly higher than that of a nitrogen-cooled screen, namely, $T_1 = 120-160$°K for vessels with one screen and $T_1 = 110-150$°K for vessels with two screens.

NOTATION

Q_{ba} and Q_{cb} – quantity of heat reaching container and screen through neck; m – rate of evaporation of liquid from vessel; L – heat of evaporation of liquid; C_p – specific heat of evaporating gas; Δi_{10}, Δi_{21}, Δi_{20} – increase in

Table

Basic Parameters of Helium Dewar Vessels Without Nitrogen Cooling Parameter

	Capacity	
	25 liter	20 liter
Outside diam., mm.	383	383
Screen diam., mm.	290	260
Diameter of container, mm.	270	240
Over-all height, mm.	1070	1020
Weight of vessel, N	392	196
Surface area of container, m^2	0.54	0.39
Thermal conductivity of insulation, including seams, W/m. deg.	$2 \cdot 10^{-4}$	$2 \cdot 10^{-4}$
Reduced emissivity of screen and container	0.01	0.01
Calculated helium loss, N/sec.	$115 \cdot 10^{-7}$	$93 \cdot 10^{-7}$
Thermal resistance of insulation, deg/W	$0.346 \cdot 10^3$	$0.42 \cdot 10^3$
Calculated screen temperature, °K	95	97

enthalpy of gas on being heated from temperature T_0 to T_1, from T_1 to T_2, and from T_0 to T_2, respectively; E_{10} and E_{21} – reduced emissivity of container and screen, and first and second screens, respectively; A_0, A_1 – surface areas of container and first screen; R – thermal resistance of vessel insulation $R = h/\lambda S_{av}$; λ – thermal conductivity of multilayer screen-vacuum insulation; λ_0, λ_1 – thermal conductivity of neck material at temperatures T_0 and T_1; α_1, α_2 – constants characterizing the temperature dependence of the thermal conductivity of the neck material; L_{ab}, L_{cb} – lengths of sections ab and cb of neck; h – thickness of insulation; S_{av} – mean isothermal surface area of insulation.

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