THERMAL LINKS FOR REDUCING THE HEAT LEAKAGE TO CRYOSTATS

N. A. Pankratov, V. S. Golubkov, and L. G. Simoshenkova

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An experimental study was made concerning the effect of thermal links on the rate of helium evaporation in a nitrogen-free cryostat with a few suspension tubes. As a result, the optimum number and location of links on such suspension tubes has been established.

When enough heat is transferred from suspension pipes to the gas, then the heat conducted in the cryostat from the outer jacket and from the radiation shields through such tubes to the liquid-helium container is either partially or completely compensated by a change in enthalpy of the evaporating helium [1]. This effect is utilized to the fullest extent in nitrogen-free helium cryostats with high-vacuum insulation [2, 3].

Some cryostats are equipped not only with a feed pipe but also with auxiliary pipes, connecting rods for the transport of specimens, and control pipes for regulating the cryostat operation [4-7]. In small-diameter pipes or in clearances between pipes which carry evaporating helium there often occur thermoacoustic vibrations with a high energy content and, as a result, the helium flow rate increases greatly. For this reason, it is preferable to install auxiliary pipes not carrying any helium and to compensate for the heat leakage with thermal links between these pipes and those carrying the gaseous helium [8].

For evaluating the efficiency of such links as well as for determining their optimum number and location along the pipes, the authors used a nitrogen-free cryostat with a 0.5 liter capacity, one radiation

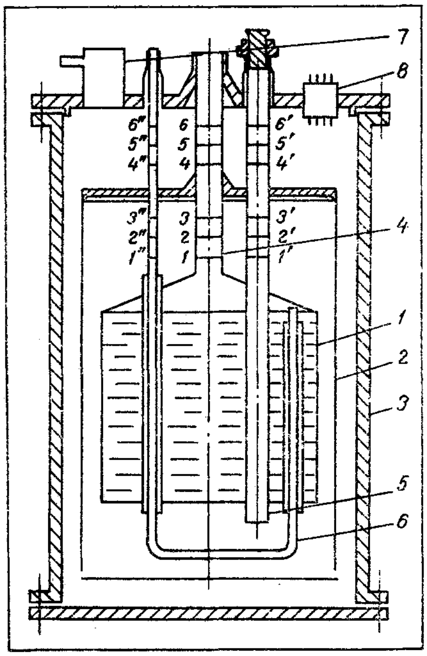

Fig. 1. Schematic diagram of the cryostat: 1) liquid-helium container; 2) radiation shield; 3) jacket; 4) feed pipe (12 mm in diameter, 0.2 mm thick); 5) pipe for transport of specimens (10 mm in diameter, 0.2 mm thick); 6) pipe for cooling the specimens (3 mm in diameter, 0.2 mm thick); 7) syphon valve; 8) vacuum-grade electrical connector.

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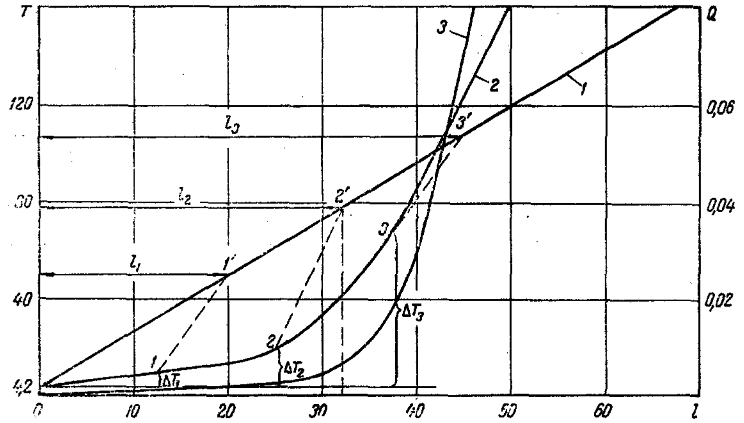

Fig. 2. Temperature profile along pipes 4 and 5 (curves 1 and 2), T (°K); amount of heat Q (W) conducted into the helium container by a pipe without helium cooling, as a function of the link location (curve 3); distance l (mm).

shield, and a high-vacuum insulation. The apparatus is shown schematically in Fig. 1. Such a cryostat is intended for attaining intermediate temperatures and its equipment includes, in addition to a feed pipe, two auxiliary pipes. The efficiency of links was estimated from the rate of helium evaporation, the latter measured with a model GZP-45 gas meter, and from the temperature of the radiation shield.

Measurements were made under two sets of conditions:

1) with pipes 4 and 6 open and with thermal links between feed pipe 4 and test pipe 5;

2) with pipe 4 closed and with thermal links between cooling pipe 6 and test pipe 5.

The efficiency of links was not evaluated with pipe 6 closed, because shutting off the flow of helium vapor through this pipe would give rise to thermoacoustic vibrations and, along with it, make the evaporation rate increase by a factor of 10 or more.

For thermal links we used technical-grade copper wire 2 mm in diameter, with the PÉV-1 insulation removed.

Strips 0.3 mm thick, cut from copper sheet, were soldered to the pipes at the contact spots. The distance between the links was 12-13 mm, the first link was installed 12-13 mm away from the container for pipe 4, and 20 mm away from the container for pipes 5 and 6.

The temperature profile along the suspension pipes 4 and 5 has been plotted in Fig. 2. The temperature profile is known to be linear along a pipe not cooled with gas (curve 1), but not so along a cooled pipe (curve 2) [9, 10]. On the basis of these curves, we have derived a relation between the amount of heat which a helium-cooled pipe conducts into the container and the link location along the pipe (curve 3). If the links are assumed ideal, then $T_1 = T_1'$, $T_2 = T_2'$, and $T_3 = T_3'$. For a pipe not cooled with gas we have

$$Q = \frac{\lambda S}{l} \Delta T. \tag{1}$$

According to the curves in Fig. 2, links become more efficient when their point of contact with a helium-cooled pipe shifts closer to the container. All this has been confirmed experimentally. In columns 3 and 4 of Table 1 are given the evaporation rates of helium and the temperatures of the radiation shield, respectively, in a setup with a single link or a combination of links (column 2). The trend of curve 3 (Fig. 2) has been fully confirmed by tests. While a 1-3' link seems most efficient of all, theoretically, inasmuch as ΔT_1 is minimum and l_3 is maximum then, a heat sink cannot be made perfect in practice and nonideal links do, therefore, change the pattern.

According to Table 1, the shield temperature depends on the rate of helium evaporation as well as on the area of contact between the cooled pipes and the shield. For example, in spite of the high rate of helium evaporation in the second test mode here, the shield temperature was approximately the same as in the first test mode, owing to the small contact area between shield and pipe 6. The rate of helium evaporation as a function of the number of uniformly spaced links is shown in Fig. 3a for the two said

TABLE 1. Efficiency of Thermal Links

Item No.	Thermal links	Helium evaporation rate, g/h	Shield temperature, °K	Note
1	No link	10,6	152	
2	1—1′	6,6	166	
3	1—2′	7,8	157	
4	1—3′	10,0	153	
5	2—1′	8,0	168	Pipes 4 and 6
6	2—2′	8,2	166	open
7	2—3′	9,0	155	
8	1—1′; 2—2′	7,0	170	
9	1—1′; 2—2′; 3—3′;	6,6	171	
10	1—1′; 2—2′; 3—3′; 4—4′	6,6	173	
11	1—1′; 2—2′; 3—3′; 4—4′; 5—5′	6,6	173	
12	1—1′; 2—2′; 3—3′; 4—4′; 5—5′; 6—6′	6,6	173	
13	No link	42,5	158	Installed links
14	1′—1″	27,5	170	1—1′; 2—2′
15	1′—1″; 2′—2″;	22	174	3—3′;
16	1′—1″; 2′—2″; 3′—3″	17,0	175	Pipe 4 closed
17	1′—1″; 2′—2″; 3′—3″; 4′—4″	17,0	175	
18	1′—1″; 2′—2″; 3′—3″; 4′—4″; 5′—5″	17,0	175	
19	1′—1″; 2′—2″; 3′—3″; 4′—4″; 5′—5″; 6′—6″	17,0	175	

cryostat operating conditions. Curve G represents the condition with the feed pipe and the cooling pipe 6 open, curve G' represents the condition with the feed pipe closed and with evaporation along pipe 6. According to the curves, the presence of thermal links above the shield (to the right of the shield on the diagram) has no effect on the rate of helium evaporation, inasmuch as the shield itself constitutes an efficient thermal link.

The rate of helium evaporation is shown in Fig. 3b as a function of the link 1 location along the helium-cooled pipe. According to Fig. 3b, the rate of helium evaporation is minimum when a link is located 17 mm from the container. With three links installed along the pipe, the evaporation rate is minimum when their distances from the container are shorter than that. With a pipe shorter than 10 mm or

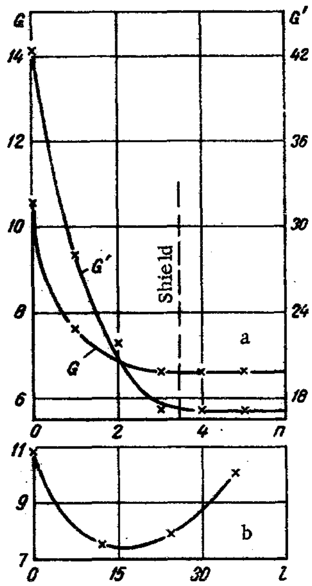

Fig. 3. Rate of helium evaporation G (g/h): a) as a function of the number of links; b) as a function of the link 1-1' location l (mm) along the helium-cooled pipe.

with a link connected directly to the container, the evaporation rate increases.

We have also studied the feasibility of reducing the heat leakage toward the helium container in the following two ways: by enlarging the cross section of an efficient single link, or by placing a second link somewhere between the first link and the shield. Neither arrangement resulted in a lower evaporation rate.

It has thus been found that three links ensure the most efficient performance of a nitrogen-free cryostat with the pipe not helium cooled. The amount of heat leaking along pipe 5 was originally 0.03 W. Thermal links reduced this amount by 70-80%. As a consequence, the rate of helium evaporation decreased at least 1.5 times.

NOTATION

Q	is the amount of heat conducted by pipe 5 into the container;
λ	is the mean thermal conductivity of the pipe material;
S	is the cross-section area of pipe 5;
l	is the length of pipe 5 from the container to the contact with a link;
ΔT	is the temperature difference between tube at respective point and helium tank;
T_1, T_2, and T_3	are the temperatures of pipe 4 at the respective contact points with links;
T_1', T_2', and T_3'	are the temperatures of pipe 5 at the respective contact points with links;
G	is the rate of helium evaporation in the first mode;
G'	is the rate of helium evaporation in the second mode.

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