DETERMINING THE THERMAL RESISTANCE OF LAMINATED STACKS AT TEMPERATURES FROM 4 TO 300°K

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The thermal resistance of flat laminated metallic and nonmetallic stacks and meshes was measured under vacuum at temperatures from 4 to 300°K. The load limits at the maximum thermal resistance were also determined.

In the design and construction of containers and conduits for storage and transport of cryogenic liquids it is very important to minimize the flow of heat along supports and hangers. In some kinds of vessels this heat amounts to approximately one half the total heat leaking in. Supports built in the form of laminated stacks contribute greatly to a reduction of this heat flow [1-3].

The authors have tried to determine the thermal resistance of laminated stacks at temperatures from 77 to 4°K at the cold surface and to select the optimum range of loads under which such stacks perform most efficiently.

For this purpose we have developed and refined the design of a cryostat with a single-stage lever mechanism for loads up to 1500 kg.

The cryostat consists of a helium vat 2 and a nitrogen vat 1 (Fig. 1) fastened to center rod 3 which, for reducing the heat leaking in, is made up of three segments separated by stacks of $\delta = 0.5$ mm thick Textolite spacers.

The rod serves for transmitting the load to the specimen and, in order to prevent distortions, is connected to the cryostat cover 4 through a socket screw 5.

Specimen 6, a pair or a stack of disks 28 or 25 mm in diameter and in good contact, rests on a calorimeter 7 which is in contact with a heat source 8 welded to the bottom of the cryostat. The upper end of the specimen is at a temperature close to the temperature of the liquid filling the lower cryostat vat (i.e., at 77-4°K). The calorimeter is a rod of a material with a thermal conductivity known over the entire test range of temperatures.

The heat source is a cell in which, depending on the test conditions, either a liquid at a given temperature can generally be circulated or a heater element can be installed.

In order to prevent lateral heat leakage to the specimen and to the calorimeter from the heat jacket, they are both covered with multilayer insulation and a shield along which the same temperature difference is maintained. In our experiment the temperature difference between shield and calorimeter was checked with a differential thermocouple and did not exceed 3°K, resulting in a 2-4% error.

For an easier mounting of the specimens and the calorimeter, they were pressed, prior to their installation in the cryostat, against the center rod by means of Textolite pull rods 9, the latter coupled to the calorimeter through a rigid collar.

The space inside the cryostat was evacuated down to 10^{-4}-10^{-6} torr and maintained at that pressure level by means of an adsorption cartridge containing activated charcoal and mounted on the upper vat.

The temperature measuring system consists of several differential thermocouples installed along the calorimeter and the specimen so that the temperature drop across the specimen, measured with a

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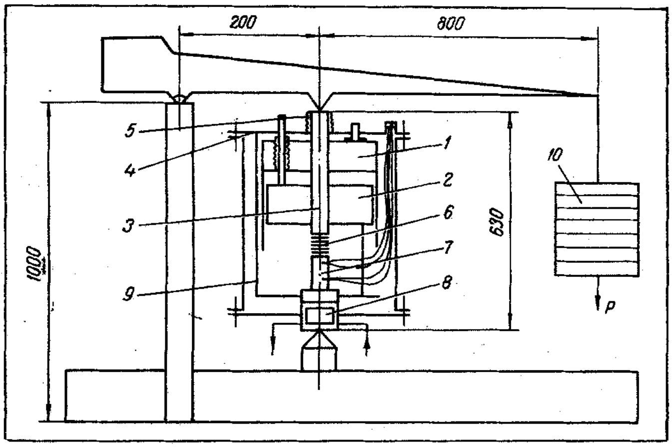

Fig. 1. Schematic diagram of the cryostat for measuring the thermal resistance of flat disks in contact.

differential thermocouple, can be checked by the temperature distribution on the calorimeter and the loading rod.

For temperature measurements we used copper–constantan thermocouples with 0.1 mm (diameter) wires in the 77-273°K range and gold–cobalt–copper thermocouples below 77°K, such thermocouples being the only ones suitable for the entire 273-4°K.

The null junctions of the thermocouples were thermostatized with liquid nitrogen and helium, the temperatures of which were checked by means of standard TSPN probes and a carbon resistor.

The thermal flux was determined from the known thermal conductivity of the calorimeter material and the measured steady-state temperature drop across it. The thermal flux readings were checked against the amounts of liquid evaporated from the lower cryostat vat, the relation between both quantities having been established in special experiments. The difference between thermal flux readings by both methods did not exceed 5%.

The thermal resistance of specimens was calculated from the measured temperature drop across them and the thermal flux passing through them under a given load:

$$R = \frac{\Delta T}{Q} \text{deg} \cdot \text{m}^2/\text{W}.$$

From the test results we then determined the thermal resistance of and the thermal flux through a specimen, as functions of the load.

The specimens tested in this cryostat were cylindrical rods, 25-28 mm in diameter and from 27 to 40 mm long, made up of flat metallic and nonmetallic disks and meshes.

The disks were made of cold-rolled stainless steel $\delta = 0.5$ mm thick with a 6-7 surface finish, of Textolite laminate $\delta = 0.5$-1.0 mm thick, and of noncorrosive metallized Lavsan gauze.

In order to establish the effect of the loading cycle on the thermal resistance of contacting disks, we performed an experiment with the specimen made up of 59 grade Kh18N10T stainless steel disks $\delta = 0.5$ mm thick each. This specimen was gradually loaded (Fig. 2a) from 0.1 to 12 MN/m^2 in 2-3 MN/m^2 steps and held at each load level for 3-12 h (point n_1). Then, in the reverse sequence, the specimen was unloaded down to the minimum level of 0.1 MN/m^2. After being held unloaded for 20 h, the specimen was again loaded up to 17 MN/m^2 (point n_2). The second loading curve coincides here with the unloading curve to point n_1. Under loads corresponding to point n_1 the thermal resistance of the specimen seems to have decreased somewhat from its value during the first loading.

The test results for a single disk are compared in Fig. 2b with the data from [2]. Our test values agree within the limits of measuring accuracy, which is an indicator of their reliability.

Values of the thermal flux and of the thermal resistance, both as functions of the load, are listed in Table 1 for the few materials with temperatures 77-273°K at the respective ends.

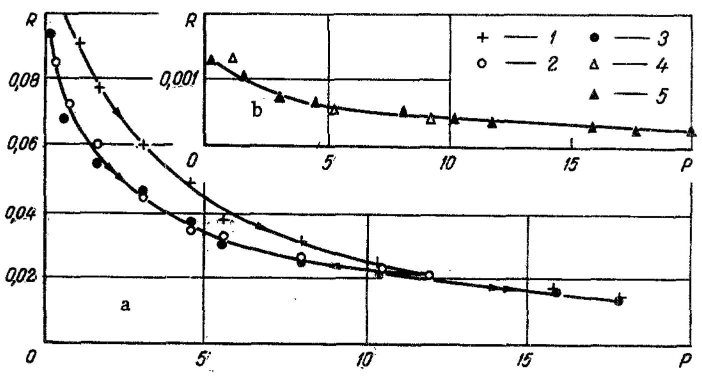

Fig. 2. Thermal resistance: a) stack of grade Kh18N10T steel disks, 59 pieces $\delta = 0.495$ mm thick each; b) single disk of grade Kh18N10T steel; temperature at the cold end: 1) first loading; 2) unloading; 3) second loading; 4) data from [2]; 5) test results.

TABLE 1. Thermal Resistance of Specimens, T_{ee} = 77-273°K

P_{sp}	Grade Kh18N10T steel, n=59 pcs, δ = 0.5 mm		Grade Kh18N10T steel, n = 67 pcs, δ = 0.4 mm		Textolite, n = 25 pcs, δ = 1.04 mm		Textolite + grade Kh18N10T steel mesh, n = 19+19 pcs		Textolite + grade Kh18N10T steel mesh, n = 18+18 pcs	
	Q	R_n	Q	R	Q	R	Q	R	Q	R
0,53	2770	0,0672	662	0,298	518	0,377	—	—	1059	0,184
1,29	3480	0,053	—	—	—	—	—	—	—	—
1,59	—	—	754	0,259	571	0,343	464,6	0,427	1174	0,166
2,95	3980	0,0454	978	0,199	658	0,296	511	0,389	1394	0,139
4,48	4833	0,0366	1025	0,189	823	0,235	643	0,310	—	—
5,33	5864	0,0294	1155	0,168	938	0,205	685,4	0,290	1824	0,105
7,86	6607	0,0257	1223	0,158	1062	0,181	689	0,287	—	—
10,2	7507	0,0219	1276	0,152	1157	0,166	777	0,255	2159	0,088
11,89	8086	0,02	—	—	—	—	—	—	—	—
14,35	—	—	1386	0,140	1309	0,146	800	0,248	2407	0,078
15,79	9716	0,0159	1418	0,136	—	—	826	0,24	—	—
17,54	11017	0,0136	1460	0,132	1382	0,139	849	0,233	2464	0,076

On the basis of this test series, one may conclude that the maximum thermal resistance is obtained with supports made up of alternating Textolite disks and stainless steel meshes. Evidently, the thermal resistance of a support will increase with decreasing thermal conductivity and increasing hardness of the material. Supports made up of metallic disks in succession offer the lowest thermal resistance of all.

In the second test series we have established the limits of specific loads under which supports made up of various materials offer the highest thermal resistance. The experiment was performed on a following specimen: the load on the specimen was increased stepwise to a definite level (threshold n_1, n_2, n_3, n_4), whereupon the specimen was unloaded to the minimum level and then loaded again stepwise to the next higher threshold. In this way, during the test a specimen was successively loaded and unloaded over the 0.1-22.2 MN/m^2 range.

Typical curves representing the thermal resistance as a function of the load are shown in Fig. 3a, b for a specimen of grade PÉTFL insulation and for a specimen of Textolite $\delta = 0.5$ mm thick alternating with perforated noncorrosive meshes, with temperatures 77-273°K and 15-273°K at the respective ends.

Thus, the loading and unloading curves form a hysteresis loop for each specimen, and raising the load limit causes a downward shift of these hysteresis curves. The thermal resistance of specimens comprising steel meshes with a 40% perforation area is twice as high as that of the specimen with solid disks.

A comparison of these results with those of earlier tests involving other meshes suggests the advisability of using meshes with a high porosity for supports. The thermal resistance of specimens is higher with 15-273°K than with 77-273°K temperatures at the respective ends, with approximately the same (within 10%) steady-state thermal flux in each case.

In Fig. 3c are shown the results of tests involving a specimen made up of Textolite disks $\delta = 1.00$ mm thick and steel meshes $\delta = 0.4$ mm thick, with grade Kh18N10T stainless steel spherical segments

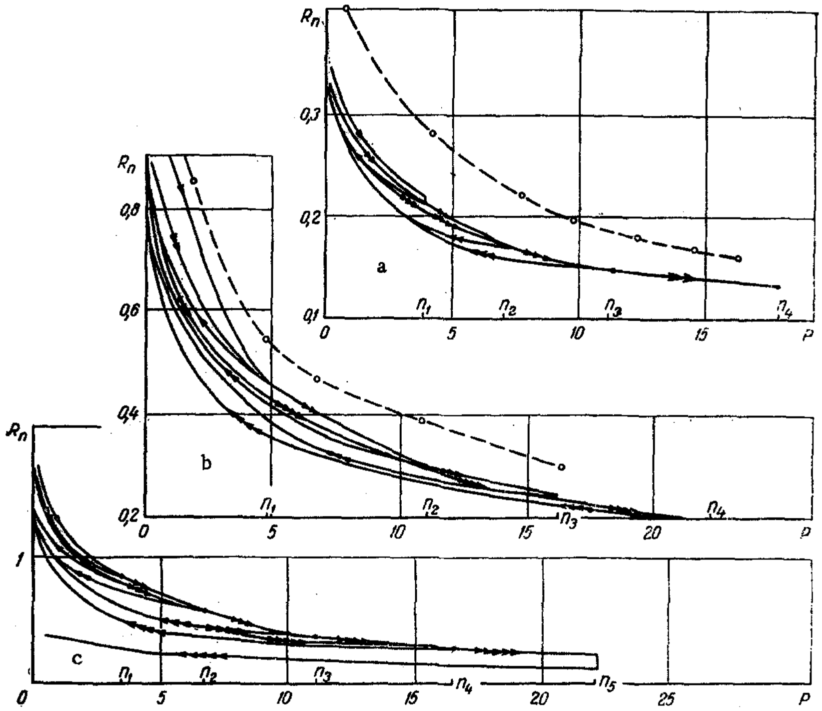

Fig. 3. Thermal resistance of specimens: a) stack of PÉTFL insulation; b) stack of alternating Textolite disks (δ = 0.5 mm) and grade Kh18N10T steel meshes (δ = 0.1 mm); c) support with grade Kh18N10T steel spherical segments; dashed lines) 18-273°K at the respective ends; solid lines) 77-273°K at the respective ends.

at both ends. An analysis of the relation R = f(P) indicates a higher thermal resistance of this specimen than of the similar one with just alternating Textolite disks and steel meshes. The most favorable conditions for such a specimen prevail within the load range up to 7 MN/m² (thermal resistance R = 1.6-0.6 deg · m²/W), inasmuch as a spherical segment of the support is then evidently in a state of elastic strain. The performance range of such a support can be extended (R can be increased by using stronger and harder materials for a spherical support).

Holding the support under the maximum test load of 22.2 MN/m² for 60 h lowered the thermal resistance of the specimen with Textolite disks and steel meshes.

NOTATION

Q	is the thermal flux through a specimen, W/m²;
R	is the thermal resistance of a specimen, deg · m²/W;
P	is the load on a specimen, MN/m²;
δ	is the disk thickness, m;
l	is the specimen length, m;
ΔT	is the temperature drop across a specimen, °K;
n_1, n_2, n_3, n_4	are the load limits, MN/m²;
T_{ee}	are the temperatures at both ends of a specimen, respectively.

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