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INSULATION PERFORMANCE FOR INDUSTRIAL VESSELS CONTAINING LIQUID N_2 AND H_2

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A screenless method of using the cold in the vapor is found to be highly effective.

The performance in thermal shielding for cryogenic vessels in substantially dependent on how far use is made of the cold in the coolant vapor. We have found that maximum use can be made of this for small nitrogen vessels by a screenless method, i.e., by providing good contact between the layers of screening-vacuum insulation and the neck of the vessel throughout its length [1]. Particular interest therefore attaches to evaluating the performance of this simple method on nitrogen-free vessels containing liquid hydrogen, where the reduction in heat leak can attain a factor of 5-8. At present, there are commercial hydrogen vessels fitted with nitrogen guard jackets, which makes them heavy and complicates their use.

We have measured the heat transfer and performance in using the cold from nitrogen vapor or parahydrogen in a commercial Kh-34B vessel in various styles (Table 1). The heat transfer to the coolant vapor was evaluated by means of a standard polystyrene plug or a glass plug with vacuum-porous insulation. In the latter case, the vapor was passed through the central channel or through a gap between the plug and the neck. The neck was made of fiberglass plastic and was 210 mm long, diameter 60 mm, and wall thickness 1.2 mm. Outside, the neck was covered with 6-8 layers of EVTI-7 glass cloth. In the standard vessel, the insulation package had good thermal contact with this layer, while to eliminate it, we also made a vessel in which the insulation and the neck were separated by a gap of 2 mm. The insulation pack had an average thickness of 70 mm and consisted on PET-DA screens and new particularly effective inserts made of USNT-10 synthetic fibers containing carbon adsorbents.

Table 1 shows that the heat leaks to the hydrogen are less by a factor of three than to nitrogen. In these experiments, the polystyrene plug was cemented on all sides with a film of PET-DA. In the absence of that film, the hydrogen vapor diffused into the plug, which increased the heat leak appreciably. During the experiments lasting 1.5 months, there was no deterioration in the leakage due to hydrogen diffusing through the wall of the fiberglass neck.

We evaluated the insulation characteristics and the cold use by our method of calculating the thermal shielding [1, 2], which involves solving nonlinear two-dimensional conjugate thermal conduction equations for the plug and insulation pack, the one-dimensional case for thermal conduction in the neck with allowance for the heat transfer with the coolant vapors, and the radiative and conductive heat exchange between the outer wall of the neck and the insulation pack.

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TABLE 1. Heat Leaks to Kh-34B Vessels

Vessel modification	Coolant	Leak, W: measured	Leak, W: calculated	Leak, W: calculated for absence of vapor	Vapor cold use
With polystyrene, no gap	N_2	0,25	0,24	0,40	1,65
	H_2	0,079	0,098	0,49	5,0
With glass plug, no gap	N_2	0,32	0,31	0,50	1,61
	H_2	0,086	0,103	0,53	5,14
With glass plug (central channel), no gap	N_2	0,46	0,44	0,50	1,14
	H_2	0,26	0,28	0,53	1,89
With polystyrene and gap	N_2	0,32	0,29	0,40	1,38
	H_2	0,22	0,21	0,49	2,33
With glass plug and gap	N_2	0,40	0,35	0,50	1,43
	H_2	0,22	0,21	0,53	2,52
With glass plug (central channel) and gap	N_2	0,50	0,50	0,50	1,0
	H_2	0,29	0,34	0,52	1,56

Calculations, calorimetric tests, and experiments with the Kh-34B vessels gave a single formula relating the thermal conductivity of the insulation λ to the temperature T:

$$\lambda = 5{,}4\cdot 10^{-3} + 3{,}78\cdot 10^{-3}T - 1{,}62\cdot 10^{-5}T^2 + 8{,}37\cdot 10^{-8}T^3.$$

This function describes the heat leak to vessels containing liquid nitrogen with an accuracy of 5-10%, or ones containing hydrogen, 10-20%, which is determined by the accuracy of the available data on the thermal characteristics for the materials. The insulation thermal conductivities were correspondingly 0.78 and 0.66 μW/cm·K. Previously, standard insulation containing EVTI-7 inserts had given λ = 1.2-1.4 μW/cm·K [1] for a Kn-34B nitrogen vessel, which is worse by about a factor 1.5-1.7 than for the USNT-10 material, which shows that a good vacuum was obtained in the insulation layers on account of the carbon adsorbent there, which can be outgassed on heating to 100-120°C.

The marked reduction in heat leak to the liquid nitrogen is due to the high performance in the screenless method of using the vapor cold. On nitrogen, the working time when the vapor cold was used was increased by a factor 1.65, and on nitrogen, by a factor 5.1, which are close to the theoretical limits: 1.67 for N_2 and 7.44 for H_2. These measurements and calculations also show that it is desirable to use nitrogen-free vessels for storing liquid hydrogen and such vessels can have fiberglass necks and polystyrene plugs cemented to PET-DA films.

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