A NEW METHOD OF REDUCING CONTACT HEAT TRANSFER IN VACUUM-SCREEN INSULATION

T. A. Kurskaya, V. F. Getmanets, and B. V. Grigorenko

UDC 536.021

A heat treatment method is proposed for vacuum-screen insulation that substantially reduces the contact heat transfer and halves the heat flux. The performance is illustrated on cryogenic pipelines with various forms of insulation.

The thermal characteristics of vacuum-screen insulation (VSI) on vessels (1-2 μW/cm•K) and pipes (2-6 μW/cm•K) are much worse than those measured on a planar calorimeter (0.3-0.5 μW/cm•K). There is an appreciable increase in the heat flux as the VSI packet thickness increases, which is due to elevated heat transfer through the gas and contact conduction.

There are fairly effective ways of reducing the gas component: perforated or punched diffraction screens (these provide high gas permeability), prolonged outgassing at high temperatures, and packing materials containing adsorbents.

At the same time, some methods of reducing the contact transfer are not very effective. The Dimplar type of insulation has inserts composed of corrugated polyethylene terephthalate films aluminized on both sides, which leads to the largest loss of performance (5-10 μW/cm•K). A better effect is obtained with corrugated screens (2-5 μW/cm•K). However, the considerable corrugation height (1.5-3 mm) does not allow one to use these VSI with packing densities more than 6-8 screens per cm. For this reason, and also because there is deterioration in the screen blackness on drawing in a die, such insulation shows considerable radiative heat transfer. Therefore, the main use is made of VSI with crumpled screens, where the optical parameters deteriorate only slightly and the contact heat transfer is acceptable for vessels.

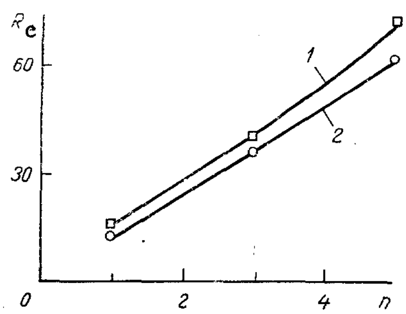
However, this insulation also has comparatively poor characteristics for cryogenic pipelines (2-6 μW/cm•K) even with small thicknesses (3-10 mm) [1].

As a VSI packet is thin and has high gas permeability (the insulation on a small pipeline is usually mounted as a spiral strip, width not more than 15-20 mm), the gas component can be taken as negligible. A packing density of 20 screens/cm or more may be used on a pipeline (to eliminate gaps at the junctions between layers) with more than 5-7 screens, in which case the radiative component is also fairly small (less than 0.5 μW/cm•K) [2]. There is a marked increase in the blackness (by a factor 2.5-3) [2] for cold screens open on the warm-wall side, which falls rapidly as the number of screens in a packet is increased above 5-7 and the temperature of the outer screen exceeds 210 K [2]. Then the main contribution to the loss in a cryogenic pipeline having a small diameter comes from the contact component. There is a marked increase in that component for a small pipeline (by a facotr 3-10 by comparison with a vessel) for two reasons. Firstly, gaps at the junctions between turns are eliminated if the winding is not less than 20-40 screens/cm, and this requires considerable force. Secondly, the winding force increases considerably with the number of screens (Fig. 1) because of the high VSI curvature for small diameters, so the most important problem for pipelines is to reduce the contact transfer.

We have used VSI (thickness 1.5-10 mm) on cryogenic pipes (diameters 3-12 mm) carrying liquid nitrogen in testing this new method of reducing the contact transfer [3], which involves brief heating (0.5-1 h) in the atmosphere for the VSI packet mounted on the item at the plasticity temperature for VSI screens (130-140°C for polyethylene terephahalate PET film). When the screens are heated to the thermoplastic state (which applies also to PET film inserts), they soften and take up a form in which the pressures between them vanish. The layers on cooling retain their new positions, in which there are no mounting forces. As the contact

Low Temperatures Technical Physics Institute. Academy of Sciences of the Ukrainian SSR, Kharkov. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 54, No. 3, pp. 446-450, March, 1988. Original article submitted October 11, 1986.

0022-0841/88/5403-0307$12.50



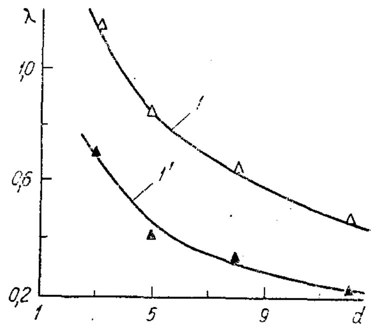


Fig. 1 Fig. 2

Fig. 1. Contact resistance for PET insulation in DA + PET corrugated form, R_c, in m^2•K/W for planar specimens (1) and cylindrical ones (2) without heating as a function of the number of screens n.

Fig. 2. Variation in conductivity λ, μW/cm•K, for DA + PET insulation, crumpled, thickness 10 mm, packing density 20 screens/cm, for pipelines having various diameters d, mm, without heating (1) and with insulation heating (1').

transfer in VSI is proportional to the layer compression force, it is much reduced by the heat treatment. The methods have been described in [4]. The screens were two-sided aluminized polyethylene terephthalate films DA) 12 μm thick, while the inserts were the recently proposed [5] crumpled PET film without coating. Then the screen and insert can be brought simultaneously to a thermoplastic state, so one expects the greatest effect from heat treatment.

Polymer film inserts have the considerable advantage of producing no silicate dust during installation and use such as is characteristic of glass or basalt fiber inserts, which improves working conditions and optimizes optical-device operation.

We also tested one-component VSI made of corrugated PET OA screens (with one-sided metallization), as well as the most effective current VSI having inserts composed of the following materials: SBSh-T glass cloth, NT-8 basalt cloth, and cloth composed of SNT-10 synthetic fibers.

Table 1 and Fig. 2 give the results. As would be expected, the main effect from heat treatment occurs with the PET film insert. With VSI 10 mm thick on 3-12 mm diameter pipes, the performance was doubled by the heating and virtually approached that of purely radiative heat transfer. At 5-8 mm diameter, the thermal conductivity (0.4-0.7 μW/cm•K) was close to the values obtained with planar calorimeters, while at 12 mm, it was actually less than the latter (0.23-0.29 μW/cm•K) in spite of gaps in the layers and deposits forming on the screens. The latter factors are decisive only for 3 mm pipe and thickness 1.5-3 mm. Under these conditions, with film inserts the conductivity before heating was 2.33 μW/cm•K, which exceeds the figures for other VSI types (1.6-1.9 μW/cm•K). After heating, the performance with the PET film increased by 27-37% (to 1.2-1.4 μW/cm•K) and attained the values characteristic of other types (1.4-1.6 μW/cm•K). However, at 10 mm thickness with the PET film (λ = 0.7 μW/cm•K), the performance was 1.5-2 times better than that with other materials (1.6-1.9 μW/cm•K). The new VSI was even more effective on 5-12 mm pipes (at all thicknesses: 1.5-10 mm).

The experiments also showed that film inserts showed an anomalous relation between conductivity and thickness, in contrast to all others.

When the thickness is increased from 1.5-3 to 10 mm, the conductivity is reduced by a factor 1.5 or more. Correspondingly, VSI with thicknesses of 1.5 and 10 mm on 3, 5, 8, and 12 mm diameter pipes gave λ of 1.43 and 0.71, 0.67 and 0.42, 0.4 and 0.34, and 0.26 and 0.23 μW/cm•K. The maximum reduction in the contact component requires the layer packing density on the pipe not to exceed 20 screens/cm; at higher densities, heating does not provide free packing without mutual compression, so the parameters deteriorate somewhat.

The new composite containing crumpled films can be used not only for pipes but also for vessels, so tests were made with a planar calorimeter (λ = 0.365 μW/cm•K) and a standard Kh-34B vessel, where the performance (without heating) was close to that of commercial VSI containing ÉVTI-7 glass cloth inserts. Therefore, one can combine the heat treatment with film

TABLE 1. Conductivities of VSI for Liquid-Nitrogen Pipes, a Flat Specimen, and a Vessel at 77-300 K

Diam. d, mm	VSI composition		Insulation thickness δ_i, mm	Density ρ, screens / cm	Conductivity λ, μW/cm·K		After, %
	screens	inserts			unheated	heated	
			Pipe				
3	PET DA	PET crumpled	2,5	20	2,23	1,43	37
3	»	»	10,0	20	1,14	0,71	38
3	»	»	1,25	40	1,63	1,19	27
3	PET OA	—	3,0	20	1,58	1,46	10
3	»	—	10,0	20	1,89	1,58	6
3	PET DA	NT-8	3,0	20	1,79	1,48	7
3	»	»	10,6	20	2,26	1,87	33
3	»	SNT-10	3,0	20	1,58	1,38	12
3	»	»	10,0	20	2,12	1,67	23
3	»	SBSh-T	3,0	10	2,1	—	—
5	»	PET crumpled	1,5	20	1,02	0,67	34
5	»	»	10,0	20	0,85	0,42	51
5	»	»	1,5	40	1,07	0,69	36
8	»	»	»	20	0,65	0,40	39
8	»	»	10,0	20	0,65	0,34	48
8	»	»	1,5	40	0,70	0,43	39
12	»	»	1,5	20	0,43	0,26	40
12	»	»	10,0	20	0,48	0,23	52
12	»	»	1,5	40	0,47	0,29	38
			Flat specimen				
160	PET crumpled	PET crumpled	6,0	19	0,37	—	—
			Kh-34B				
378	PET DA	PET DA	30—40	18—20	1,32	—	—

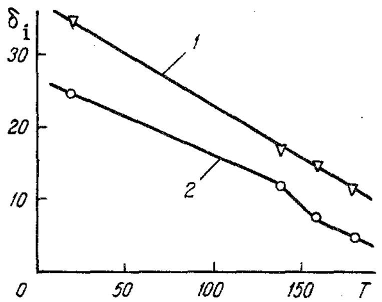


Fig. 3. Insulation thickness δ_i, mm, as a function of heating temperature T, °C, for a 160 mm diameter specimen with 10 screens, PET DA with nine PET crumpled film inserts with and without loading: 1) P = 0; 2) 18.5 g.

inserts to provide a very promising form of cryogenic insulation for units containing optical components or having complicated shapes, which may lead to marked local compression.

Effective use of this method requires optimum temperature definition. Rapid relaxation requires the maximal temperature, but the PET film should not decompose or the optical characteristics deteriorate. Brief heating to 150°C did not alter the blackness appreciably.

PET film has a glass temperature of 80-90°C and a melting point of 250-260°C; at these extreme temperatures, the crystallization rate is zero, while the maximum rate occurs at 160-180°C [6]. That range is optimal for the treatment, as Fig. 3 shows. We chose the range by recording the thickness change in a planar specimen as a function of temperature on free stacking and at 920 g/m². It is evident from Fig. 3 that the thickness in the compressed specimen fell sharply at about 140°C, which coincides with the maximal crystallization temperature. This is due to the brief treatment (0.5-1 h), which is required to eliminate the installation forces and involves partial crystallization in the amorphous PET film. The macromolecule mobility and the phase transition rate fall sharply on cooling to room temperature [6], so the layers become fixed in their new form with minimum compressive forces.

We have thus tested a simple, economical, and effective method of reducing the contact resistance in VSI. The main effect is obtained with PET film inserts. The optimum temperature, time, and packing density have been established.

NOTATION

d, pipe diameter; n, number of screens; R_c, contact resistance; T, insulation heating temperatures; δ_i, insulation thickness; λ, thermal conductivity; ρ, packing density.

LITERATURE CITED

1. T. A. Kurskaya, V. F. Getmanets, B. V. Grigorenko, and Yu. V. Kotlyar, Effective Thermal Insulation for Cryogenic Pipelines [in Russian], Preprint FTINT AN Ukr. SSR, Kharkov (1984), No. 35-84.
2. T. A. Kurskaya, V. F. Getmanets, and B. V. Grigorenko, Inzh.-Fiz. Zh., 47, No. 1, 64-71 (1984).
3. "A method of insulating cryogenic components," Inventor's Certificate No. 1262183, 4F17C3/00.
4. T. A. Vasil'eva, and V. I. Bryl', Calculating and Testing Cryogenic Systems [in Russian], Kiev (1981), pp. 51-56.
5. "Low-temperature insulation," Inventor's Certificate No. 970025, Moscow. Cl. 3, F17C3/02/F16 59/06.
6. V. V. Anokhin, Polymer Chemistry and Physicochemistry [in Ukrainian], Kiev (1971).

ANALYSIS OF THE ACCURACY FOR SOLVING PROBLEMS OF RADIANT HEAT EXCHANGE IN SYSTEMS WITH A SELECTIVELY RADIATING MEDIUM

V. I. Antonov and L. I. Zdorovova

UDC 536.3

The error in determining the resulting heat fluxes is investigated numerically in a system of bodies for a gray model and a selectively gray model of radiation.

An effective solution of problems of radiant heat exchange in systems with radiant and absorbing media can be carried out by zonal methods. The radiant medium and surrounding surfaces are divided into separate three-dimensional and surface zones, in which the temperature and thermal properties of the radiating objects are assumed to be constant [1, 2]. In this way integral equations can be reduced to algebraic equations, with the number of equations being equal to the number of zones. With increase in accuracy of calculations the number of zones increase sharply and can reach 40-50 in calculating flare burning.

If organic fuels serve as a source of energy, then, when they burn, gaseous CO_2 and H_2O are formed, which have appreciably selective spectra of absorption and radiation. In a selective-gray approximation the entire spectrum is divided into separate bands, inside of which the absorption coefficient is assumed to be constant (usually, 10-12 bands), and the system of zonel equations is solved for each band.

When solving problems with variable temperatures of volumes and surfaces (for example, heating and cooling articles in furnaces), the radiant heat fluxes should be determined at each step of time. This increases considerably the volume of calculations both when constructing matrices of the systems of linear equations of the zonal method (determining the generalized angular coefficients), and also when solving these systems.

Therefore, an increase in the accuracy of determining heat fluxes in a radiating system by using a more detailed description of the process can lead to a volume of calculations that exceeds considerably the possibilities of even contemporary computers, especially for problems with variable temperatures of surfaces and volumes.

M. I. Kalinin Leningrad Polytechnic Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 54, No. 3, pp. 450-455, March, 1988. Original article submitted September 25, 1986.

0022-0841/88/5403-0310$12.50