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BRIEF COMMUNICATIONS

EFFECTIVE THERMAL CONDUCTIVITY OF MULTILAYER VACUUM INSULATION AS A FUNCTION OF ITS THICKNESS

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The dependence of the effective thermal conductivity of multilayer vacuum insulation on its thickness has been experimentally determined.

When multilayer vacuum insulation is used on industrial vessels its effective thermal conductivity increases, sometimes by several times [1,2], as compared with the calorimetric data. As a rule, the insulation used in industrial applications is more than 40 mm thick, whereas in calorimetric measurements the thickness of the specimen is generally 10–20 mm. It has been suggested that the deterioration in the insulating properties is attributable to technical factors (local increases in packing density, butt joints, thermal contraction of the foil, etc.) [3]. However, even when a near-calorimetric packing density is retained, the thermal properties still deteriorate. On the other hand, in calorimetric measurements certain authors have observed an increase in λ_{eff} with increase in the thickness of the investigated specimen. This effect is either simply noted without explanation [4] or attributed to a possible experimental error [5], since in flat and cylindrical calorimeters it is very difficult to eliminate the error due to edge effects, especially when the thickness of the specimen is increased. Indeed, if at a pressure in the calorimeter cavity of less than $1 \cdot 10^{-3}$ N/m^2 the heat transfer through a specimen of multilayer vacuum insulation is regarded only as heat transport by radiation and solid conduction, with heat transport by the residual gases neglected, it is impossible to explain the dependence of λ_{eff} on δ.

In [6] it was shown that heat transport by the residual gases between the layers of insulation has an important influence on the total heat flux even at a pressure in the insulation cavity of less than $1 \cdot 10^{-3}$ N/m^2. Accordingly, it was assumed that if the absolute residual pressure in the layers of insulation increases with increase in its thickness (as a result of the deterioration of the pumping conditions), then in insulation of this kind λ_{eff} is a function not only of the temperature but also of the thickness of the insulation.

To check this assumption, we conducted a series of experiments on two calorimeters, one of which was described in [7], while the second is shown schematically in Fig. 1.

Unlike the cylindrical calorimeter [5], that shown in Fig. 1 eliminates edge effects, and the insulation-laying and evacuation conditions are similar to those encountered in practice in connection with small vessels. In our view, this apparatus therefore has considerable advantages over the cylindrical calorimeter.

The experiments were performed on the following types of insulation:

1) annealed aluminum foil 14 μ thick, separated by layers of SBR-M glass paper 40 μ thick (diameter of elementary fibers 5–7 μ)—type I, or EVYI-15 glass wool 0.15 mm thick (diameter of elementary fibers 15–18 μ)—type II;

2) crumpled polyethylene terephthalate film 12.5 μ thick aluminized on one side—type III.

The experiments required particularly high accuracy; accordingly, measures were taken to create identical conditions for all the specimens with respect to packing density and the level of the vacuum in the calorimetric cavity ($2–4 \cdot 10^{-5}$ N/m^2), while on the calorimeter of [7] the temperature at the guard ring was kept close to the temperature distribution in the specimen and the same annular gap was preserved between the specimen and the guard ring. We used the free packing density for insulation of type I and type III, namely, 28 sheets of foil per cm and 16 layers per cm,

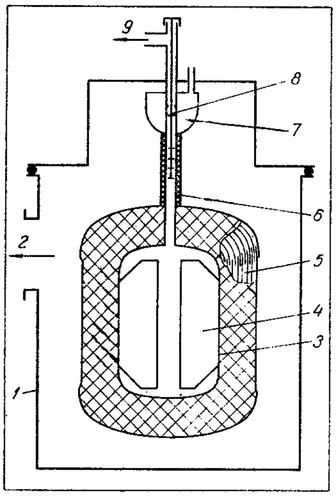

Fig. 1. Diagram of calorimeter used for investigating insulation on model vessels: 1) vacuum chamber; 2) to pumping system; 3) cylindrical vessel (20 *l*); 4) temperature compensators; 5) test insulation; 6) thermal insulation; 7) guard vessel; 8) screen; 9) to gas flow measuring system [7].

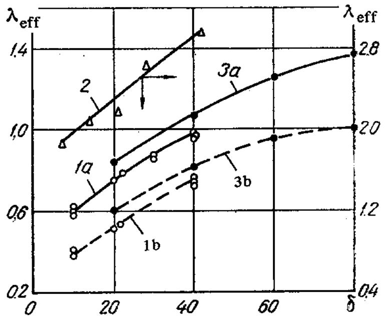

Fig. 2. Effective thermal conductivity of certain types of multilayer vacuum insulation as a function of thickness: 1) type I (a–300–77° K, b–300–20); 2) type II (300–77); 3) type III (a–290–77, b–290–20).

(free packing—7 sheets per cm). The insulation of type II was tested at a packing density of 10 sheets per cm (free packing—7 sheets per cm). The insulation of types I and II was tested on the flat calorimeter of [7], that of type III on the calorimeter shown in Fig. 1. The total experimental error did not exceed ±5% for the flat calorimeter and ±8% for the calorimeter shown in Fig. 1.

The results presented in Fig. 2 correspond to the steady-state regime, which developed in the course of 1–5 days. It is clear from the graph that the effective thermal conductivity increases with increase in the thickness of the insulation. This is easily explained, if one considers that as the thickness of the insulation increases the gas evacuation conditions deteriorate, while the release of gases increases owing to the increase in the number of layers, which leads to a corresponding increase in the pressure in the insulation. Consequently, the λ_{eff} of multilayer vacuum insulation should be treated as a function not only of temperature but also of pressure, i.e., $\lambda_{eff}(T, P)$, where $P = P(\delta)$.

NOTATION

q—specific heat flux, $\mu W/cm^2$
λ_{eff}—effective thermal conductivity, $\mu W/cm \cdot {}^{\circ}K$
δ—thickness, mm
P—pressure, N/m^2

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