The total enthalpy of the cylindrical layer of liquid per unit length of generator is

$$I = 2\pi a^2 c \int_{\xi}^{1} \frac{t}{v} \rho\, d\rho = \frac{2\pi a^2 c}{v_0 \delta (2 - \mathrm{Nu}\,\vartheta)} \frac{\exp(\vartheta - \vartheta_1)}{\xi(1 - \mathrm{Nu} \ln \xi) + \beta} \times$$

$$\times \left\{ \left[[\vartheta_1 (1 - \ln\xi) - \varepsilon]\xi + \beta\vartheta_1 \right] (1 - \xi^{2-\mathrm{Nu}\vartheta}) + \right.$$

$$\left. + \mathrm{Nu}\, \varepsilon\xi \frac{\xi^{2-\mathrm{Nu}\vartheta} [1 - (2 - \mathrm{Nu}\,\vartheta) \ln \xi] - 1}{2 - \mathrm{Nu}\,\vartheta} \right\}; \qquad (21)$$

when $\delta = 0$

$$I = \frac{\pi a^2 c}{v_0} \{ 2nt_1 - \Theta [2n + (1 - 2n) \ln (1 - 2n)] \}, \qquad (22)$$

where t_1 and Θ must be taken with regard for (9).

NOTATION

c is the specific heat, $J \cdot kg^{-1} \cdot degree^{-1}$; I and m are the total enthalpy, $J \cdot m^{-1}$, and mass, $kg \cdot m^{-1}$ of the cylindrical layer of liquid with unit length of generator; ν is the specific volume, $m^3 \cdot kg^{-1}$; r is the radius vector, equal to a on the solid cylindrical surface, and b on the free surface of the liquid, m; t is the temperature, °K; $\Theta = dt/d \ln r$; α, δ and λ are the coefficients of heat transfer, $W \cdot m^{-2} \cdot degree^{-1}$, thermal expansion, $degree^{-1}$, and thermal conductivity, $W \cdot m^{-1} \cdot degree^{-1}$; $\Delta t_e = t_{e1} - t_{e2}$, $\Delta t = t_1 - t_2$, $\Delta t_1 = t_{e1} - t_1$, $\Delta t_2 = t_2 - t_{e2}$ are the temperature drops; $n = m\nu_0 / 2\pi a^2 < 1/2$, $\mathrm{Nu} = \alpha_1 a/\lambda$ is the Nusselt number, $\varepsilon = \delta\Delta t_e$, $\vartheta - \delta\Delta t_1$, $\vartheta_1 = \delta t_{e1}$, $\rho = r/a$, $\xi = 1 - \mu = b/a$, $\xi_0^2 = 1 - 2n \exp(\vartheta_1)$, $h = \xi - \xi_0$ are dimensionless quantities. Subscripts 1 and 2 relate, respectively, to $r = a$ and $r = b$; e relates to the external media.

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USE OF INVERSE METHODS OF HEAT CONDUCTION TO DETERMINE CONDITIONS OF UNSTEADY HEAT TRANSFER

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1. Determination of radiative-convective heat transfer on a heated cylinder [1, 2]. This was carried out in investigations of bimetallization of sliding bearings used in shipbuilding [3]. A bushing of St 15 steel had diameters of 82 and 62 mm, and length 100 mm. A batch of OTsS 6-6-3 bronze was fused in an electric arc and uniformly distributed over the inside surface of the bushing by centrifugal force. The rotating product was cooled on the outside with air, and on the inside with nitrogen. The heat balance of this kind of an unsteady technical process may be set up only with the aid of inverse methods of heat conduction [1, 4, 5]. Pt versus Pt-Rh thermocouples were embedded at distances of 31 and 38.5 mm from the axis, and their emf's were recorded on a EKVO-III-8711 strip potentiometer. The temperatures, measured to an accuracy of 5° at a speed of 750 rpm, are shown in Table 1, which also gives the temperature of the cooled surface, calculated from formula (3.18) of reference [1]. The first three terms of the series were used to calculate this.

The thermal diffusivity a [6] was taken at 1273° K, equal to 0.065 cm^2/sec, and the thermal conductivity was $\lambda = 0.2375$ W/cm · °K. By differentiation with respect to the coordinate $\nu = r/r_1$ we calculated the heat fluxes

$$q = -2\pi\nu\lambda\, \partial t(\nu, \tau)/\partial \nu, \qquad (1)$$

the heating $\nu = \nu_i = 1$, dissipation $\nu = \nu_e = 1.323$, and accumulation $q_a = q_i - q_e$.

The graph of the modified Biot number

$$\mathrm{Bi} = [2\pi\nu_e\, \partial t(\nu_e, \tau)/\partial\nu]/[t(\nu_e, \tau) - t_e] \qquad (2)$$

outwardly resembles the curve for q_i (Fig. 1), increasing from 1.2 to 5, and has a stationary value of 2.22.

2. Experimental determination of the unsteady contact heat transfer of a heated hollow sphere. St 45 steel spheres of diameter 61.00 and 159.75 mm were used. The sphere was positioned in sand saturated with water in a large container. The inside surface of the sphere was insulated with a 4 mm layer of asbestos from a spherical nichrome coil to which voltage was applied. Chromel-alumel thermocouples were located at $r_1 = 36.9$, $r_2 = 49.5$ and $r_3 = 75.5$ mm from the center. They were insulated with mineral fiber and located in ϕ 1.5 mm steel tubes. The temperature was recorded on a 28KVT potentiometer with scale from 273 to 473° K for the thermocouple used. The measured temperatures are shown in Table 2.

From these temperatures, in accordance with formula (5.2) of reference [1], we calculated the thermal diffusivity, which proved to be equal to 0.1292 cm^2/sec at a mean temperature of 405° K. The handbook values at 373 and 423° K are 0.1308 and 0.1269 cm^2/sec, and 0.1288 cm^2/sec was taken. From the temperatures at the edge points the temperature field of the sphere was reconstructed, according to the formula (4.17) of reference [1]:

$$q = -4\pi\nu^2\lambda\, r_1 \partial t(\nu, \tau)/\partial\nu. \qquad (3)$$

The calculated power supplied to the internal surface of the sphere is $\nu_i = 0.8266$, and that dissipated through the outside surface is $\nu_e = 2.1653$. For St 45 steel [6, 7], $\lambda = 0.474$ W/cm · °K. These quantities are shown in Fig. 2, in addition to the accumulated power q_a.

Table 1

Temperatures of Internal Points and Cylinder Surface

τ, min	T, °K			τ, min	T, °K		
	at point 1	at point 2	on cylinder surface		at point 1	at point 2	on cylinder surface
1.0	698	633	625.5	4.5	1458	1343	1311.9
1.5	963	868	851.2	5.0	1463	1373	1348.7
2.0	1023	1023	1003.3	5.5	1478	1388	1363.3
2.5	1283	1123	1084.2	6.0	1493	1403	1377.9
3.0	1353	1198	1158.6	6.5	1493	1408	1383.9
3.5	1408	1258	1218.6	7.0	1498	1413	1388.5
4.0	1443	1313	1278.5				

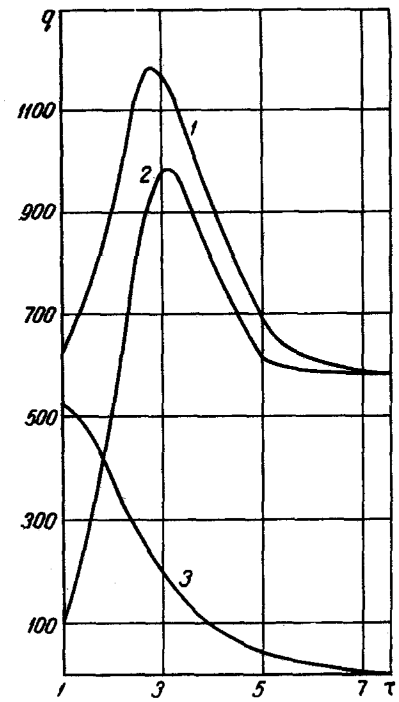

Fig. 1. Power balance for the bimetallization process (q in W/cm, τ in min): 1, 2, and 3) respectively. heat q_i, dissipation q_e, and accumulation q_a fluxes.

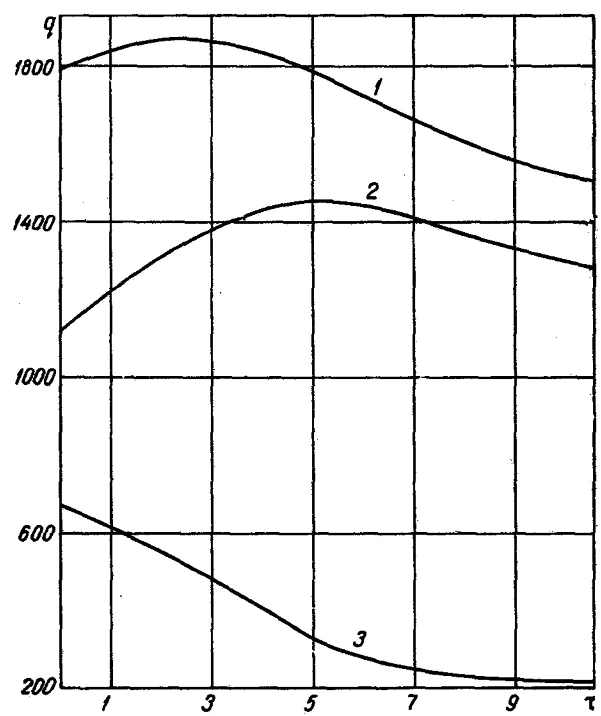

Fig. 2. Power balance for a heated sphere (q in W, τ in min): 1, 2, and 3) respectively, heating q_i, dissipation q_e, and accumulation q_a power.

Table 2

Temperatures at Internal Points of Sphere

τ, min	T, °K at point 1	T, °K at point 2	τ, min	T, °K at point 1	T, °K at point 2
0.0	409.8	371.4	5.5	432.7	393.3
0.5	412.7	374.8	6.0	433.5	394.6
1.0	415.7	377.0	6.5	434.1	395.8
1.5	418.7	379.2	7.0	434.7	397.0
2.0	421.2	381.4	7.5	435.3	398.2
2.5	423.7	383.4	8.0	435.9	399.4
3.0	425.7	385.4	8.5	436.5	400.5
3.5	427.7	387.3	9.0	437.1	401.6
4.0	429.2	388.9	9.5	437.7	402.7
4.5	430.7	390.4	10.0	438.3	403.8
5.0	431.7	391.9	10.5	438.9	404.8

3. **Existence of a maximum of dissipated power q_e.** This is due to the accumulating action of the internal layers of the body. At the start of the process the temperature of the outside surface is low, and very little heat is given out through it. The internal layers are strongly heated, and at a certain time

$$|\partial t(\nu_i, \tau)/\partial \nu| > |\partial t(\nu_e, \tau)/\partial \nu|. \quad (4)$$

After a definite time the sign of this inequality changes. This occurs when at the points $\nu = 1$ and $\nu = \Delta > 1$ of the one-dimensional field the temperatures increase:

$$t(1, H) = t_1 [1 - \exp(-\mu_1^2 H)],$$

$$t(\Delta, H) = t_\Delta [1 - \exp(-\mu_\Delta^2 H)]. \quad (5)$$

Thus, at the first point the temperature is always greater than at the second, and at the beginning of the process it quickly increases:

$$t_1 \geqslant t_\Delta, \qquad \mu_1 > \mu_\Delta > 0. \quad (6)$$

Then the main part of the heat flux, which is proportional to the difference of the temperatures indicated, takes on its greatest value at the time

$$H = \left[\ln \frac{t_1}{t_\Delta} \frac{\mu_1^2}{\mu_\Delta^2} \right] \Big/ \left[\mu_1^2 - \mu_\Delta^2 \right]. \quad (7)$$

Before this time we reach a maximum of heating power q_i, and afterwards of dissipated power q_e. When the heater is brought on slowly, when $\mu_1 \cong \mu_\Delta$, the fluxes $q(\nu, \tau)$ increase monotonically [4, 8].

REFERENCES

1. A. G. Temkin, IFZh, no. 10, 1961.
2. A. G. Gromyko, Electric Arc Method of Production of Bimetallic Bearings [in Russian], Kaliningradskoe obl. izd., 1963.
3. A. G. Gromyko and Yu. A. Nesvetaev, Sudostroenie, no. 7, 1963.
4. A. G. Temkin and G. P. Buinyachenko, Izv. AN LatvSSR, ser. fiz.-tekhn. nauk, no. 4, 1965.
5. A. G. Gromyko, Investigation of the Electric Arc Bimetallization Process in a Protective Gas Medium [in Russian], Candidate's dissertation, Kaliningrad Technical Institute of the Fishing Industry and Economy, 1964.
6. N. N. Rykalin, Calculation of Heat Processes in Welding [in Russian], Mashgiz, 1961.
7. E. R. Eckert and R. M. Drake, Theory of Heat and Mass Transfer [Russian translation], GEI, 1961.
8. G. P. Buinyachenko, Determination of Heat Transfer Parameters from Measurements in an Unsteady Plane Axisymmetric Field [in Russian], Candidate's dissertation, Riga Polytechnic Institute, 1965.

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