MEASUREMENT OF THE INTEGRAL EMISSIVITY OF NICKEL

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Test data have been obtained pertaining to the integral emissivity ε of polished nickel and of nickel after treatment with alkali-metal vapors. A universal equation is proposed for ε within the 0-1400°C temperature range.

The integral emissivity of nickel was measured with an instrument for measuring the thermal conductivity of alkali-metal vapors by the method of coaxial cylinders [1, 2].

The test specimens were made of nickel tubing whose active surfaces had been polished to a $\nabla 13$ finish. The dimensions of the cylinders were: outside diameter of inner cylinder $d = 10.703^{-0.001}$mm, inside diameter of outer cylinder $D = 11.104^{+0.005}$mm, active gap width $\sigma = 0.20$ mm, and active segment length $l = 78.7$ mm.

Inside the inner cylinder was placed a platinum heater generating a radial flow of heat. The heater consisted of one main and two standby coils. The voltage drop across the active segment was measured with a model R 307 potentiometer. Three thermocouples were installed along the inner cylinder, held against the surface with retaining rings. Three matching thermocouples were clamped against the outer cylinder.

The corresponding temperatures along the height of both cylinders did not differ by more than 0.1°C throughout the tests. The thermocouple emfs were measured with a model R 306 constant-current potentiometer.

The instrument was connected to a vacuum system consisting of a model RVN-20 prevacuum pump, a model DMN-20 diffusion pump, and three liquid—nitrogen traps. During the tests the vacuum was maintained at a residual pressure within 10^{-4}-10^{-5} mm Hg. At such vacuum levels it was permissible to disregard the residual thermal conductivity of air. As a preliminary step, the thermal conductivity of xenon, krypton, and argon was measured with this instrument first. The resulting test values were slightly lower than reliable published ones. This could evidently be attributed to the thermal resistance at the thermocouple contacts, which produced systematically higher readings of the temperature difference Δt_e. With λ_e denoting the measured thermal conductivity of an inert gas, the correction $\Delta\lambda/\lambda_e = f(\lambda_e, t)$ was found from the test results for these gases. Thus, the true thermal conductivity could be determined as follows:

$$\lambda_{tr} = \lambda_e\left(1+\frac{\Delta\lambda}{\lambda_e}\right) \qquad (1)$$

or

$$\Delta t_{tr} = \frac{\Delta t_e}{1+\dfrac{\Delta\lambda}{\lambda_e}}\,. \qquad (2)$$

Into the emissivity measurements with nickel cylinders were subsequently introduced corrections for the temperature difference Δt_e. For this purpose, values of the fictitious thermal conductivity λ_{fi} were determined for each test point and from these values, then, the corrections were found and used for calculating Δt_{tr} according to Eq. (2). These corrections turned out to be small, not larger than 1-5%. Next were found the true temperatures t_{1tr} and t_{2tr}.

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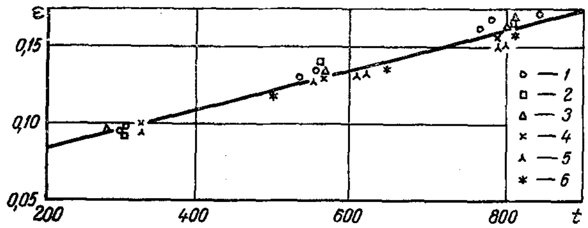

Fig. 1

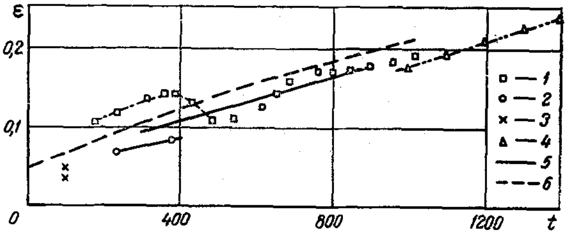

Fig. 2

Fig. 1. Integral emissivity of nickel: pure nickel (1), after a 10 h treatment with cesium vapor (2), after cesium measurement (3), before rubidium measurement (4), after rubidium measurement (5), after sodium measurement (6).

Fig. 2. Emissivity data for nickel: according to [3] (1), according to [4] (2), according to [5] (3), according to [7] (4), according to this study (5), theoretical curve (6).

The measured values of thermal flux W_{rad} varied from 0.2 to 2.0 W. The temperature differences Δt_e were read within 20-50°C.

The referred emissivity of the nickel cylinders was determined according to the formula

$$\varepsilon_{ref} = \frac{W_{rad}}{\sigma F_1 \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]} . \tag{3}$$

The referred emissivity ε_{ref} and the integral emissivity of a system of coaxial cylinders are related as follows:

$$\varepsilon_{ref} = \frac{1}{\frac{1}{\varepsilon} + \frac{F_1}{F_2}\left(\frac{1}{\varepsilon} - 1\right)} , \tag{4}$$

with F_1 and F_2 denoting the respective surfaces of the cylinders and $F_1/F_2 = d/D = 0.964$.

The integral emissivity of nickel was defined as

$$\varepsilon = \frac{1 + \frac{F_1}{F_2}}{\frac{1}{\varepsilon_{ref}} + \frac{F_1}{F_2}} . \tag{5}$$

With the same test apparatus we measured also the thermal conductivity of cesium, rubidium, and sodium vapors within temperatures from 400 to 800°C and under pressures from 5 to 100 mm Hg.

The cesium tests lasted for 150 h, the rubidium tests lasted for 200 h, and the sodium tests lasted for 50 h.

The integral emissivity was first of all determined for pure polished nickel at temperatures t = 300, 308, 551, 565, 780, 791, 840°C and was found to be 0.095, 0.097, 0.133, 0.135, 0.163, 0.166, 0.172 respectively. The surfaces of the cylinders were then placed for 10 h in an atmosphere of cesium vapor. The emissivity of nickel ε was then measured before and after the thermal conductivity of cesium vapor had been measured. According to Fig. 1, both sets of values were in close agreement. The ε values for nickel obtained in subsequent tests with rubidium and cesium also closely agreed with the ε values obtained with cesium. The deviation from the averaging curve is 4%.

An estimate of the measurement accuracy against formula (3) has shown that the maximum error does not exceed 6%. The results are compared in Fig. 2 with the most reliable published values.

The radiation characteristics of nickel were studied experimentally in [3] within temperatures from 190 to 1010°C. The results were represented there in form of the equation $E = C'T^n$, with n varying from 4.62 to 4.70 over the entire range of test temperatures. In our study here those results were evaluated in terms of the Stefan–Boltzmann equation. The $\varepsilon = f(t)$ curve is shown in Fig. 2. The bending of the curve in the low-temperature region does not concur with the test results obtained by other authors. Such a bending of the curve can hardly be attributed to the phase transformation, which for nickel occurs at about 380°C, inasmuch as the emissivity of several metals is known to be almost insensitive to the phase transformation and the magnitude of any effect it may have would be well within the magnitude of the measurement error (5-10%).

H. Schmidt and Furtmann [4] have obtained two test points for ε at relatively low temperatures.

H. Schmidt and E. Eckert [5] show only one point each for polished and for dull nickel at 100°C.

A. H. Sully et al. [6] measured the emissivity of nickel at temperatures from 350 to 580°C. Unfortunately, they did not list the numerical values and made it difficult to read absolute values off a small diagram.

A. V. Logunov [7] shows test data for nickel at temperatures from 1000 to 1400°C.

According to Fig. 2, our test data are in satisfactory agreement with the data in [3-7].

It would be of interest to analyze the well known theoretical relation between emissivity ε and the thermal conductivity λ(W/m·°C) of metals [8]:

$$\varepsilon = 1.27 \cdot 10^{-3} \frac{T}{\sqrt{\lambda}}, \tag{6}$$

where T is the absolute temperature (°K). Calculations based on this relation are shown in Fig. 2. The λ values here have been taken from [9].

According to Fig. 2, the theoretical values of emissivity are somewhat higher than its test values. This difference from the averaging curve is 10%. Moreover, the theoretical curve does not bend noticeably within the range of phase-transformation temperatures for nickel.

The spread of all test data within the 500-1400°C range is ±5%. At lower temperatures the spread is somewhat wider. This is evidently explainable by the much smaller thermal fluxes and much stronger end effects in cylinders at low temperatures.

For the 500-1400°C temperature range one may use the universal equation, which fits all the test data within ±5%

$$\varepsilon = 0.05 + 0.135 \cdot 10^{-3} t, \tag{7}$$

with t in °C.

The same equation can be used also for the 0-500°C temperature range, but the accuracy here may be as poor as ±10%.

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