# INVESTIGATION OF THE THERMAL CONDUCTIVITY OF THIN-WALLED NICKEL TUBES

B. E. Neimark and T. I. Bykova

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An account is given of an experimental investigation of the thermal conductivity of thin-walled nickel tubes in the temperature range 20-500°C by the method of Jager and Disselhorst.

It is more difficult to determine the thermal conductivity of specimens in the form of thin-walled tubes than that of rod-type specimens. The main source of error in determining the thermal conductivity of rods by the continuous method is heat transfer from the lateral surface of the specimen to the surrounding medium: the larger the ratio of the lateral surface area to the cross sectional area of the specimen, the greater the possible error in determining the thermal conductivity. This ratio is appreciably greater for tube specimens than for rods.

The second significant source of error for tube specimens is heat transfer inside them, since under test conditions a certain temperature difference exists along the length of the specimen. Although heat transfer by convection may easily be avoided by evacuating the hollow tube, that due to radiation cannot be avoided even under high vacuum. The presence of heat transfer inside the specimen also leads to a considerable overestimate in the measured values of the conductivity. The higher the test temperature, the greater this overestimate.

An experimental investigation of the thermal conductivity of two nickel tubes was carried out by the method of Jager and Disselhorst [1-3]. Number 1 had diameters 8.51/8.025 and No. 2 12.96/11.025 mm. The metal of the first tube had a Ni + Co content of 99.87%, while the purity of that of the second tube was not determined.

The $\lambda$, L, $\rho$, and the mean temperature of the specimen were measured in accordance with the following formulas:

$$\lambda = \frac{VI}{2(\Delta t - \varepsilon N)} \cdot \frac{l}{S}, \tag{1}$$

$$L = \frac{V^2}{2(\Delta t - \varepsilon N)T}, \tag{2}$$

$$\rho = \frac{V}{I}\frac{S}{l}, \tag{3}$$

$$t_{av} = t_2 - \Delta t/3. \tag{4}$$

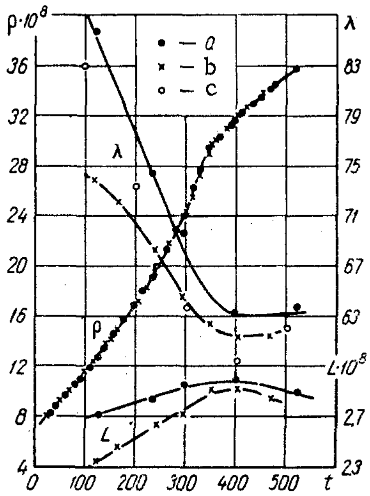
The equipment used was first prepared for the investigation of rod specimens and has already been described [4, 5]. The specimen, located in a screened oven, is heated by a constant current from a battery of capacity $368 \cdot 10^5$ coulomb. The lateral surfaces of the specimen were isolated from the oven walls by zirconia powder. A vacuum of the order $133.322 \cdot 10^{-4}$ N/m$^2$ (N = newton) was maintained in the chamber.

The temperatures of the specimen and the oven wall were measured by platinum/platinum-rhodium thermocouples. The current passing through the specimen, the potential drop in it, and the thermocouple emf's were measured with a potentiometer system.

Good insulation of the lateral surface of the specimen and an adequate vacuum considerably reduced heat transfer between the lateral surface and the oven walls and permitted a very small value of $\varepsilon$N. In the tests $\varepsilon$N usually varied within the limits 0-0.3°C. When the temperature difference maintained in the specimen was not less than 20°C, the accuracy in determing $\lambda$ was ± 2%, L − ± 1.5%, and $\rho$ − ± 0.5%.

In order to exclude heat transfer due to radiation inside the tube, it was filled with well tamped zirconia powder. The length of the experimental part of the tube specimen (the distance between the extreme thermocouples on the specimen) was the same as for the rods, namely 80 mm. The tube was then placed in the screened oven, and, as usual, the lateral surface of the specimen was insulated from the oven walls with zirconia powder. The temperature difference $\Delta$t in the specimen increased with the test temperature. In testing tube No. 1, $\Delta$t increased from 11°C at 120°C to 67°C at 500°C, and with tube No. 2 from 4°C at 100°C to 29.4°C at 470°C. The thermal conductivity and the Lorentz number were determined every 50 to 100°C. The electrical resistivity was determined every 5 to 10°C, since it is not necessary to measure $\rho$ under steady thermal conditions.

The results of the investigations are presented in the figure and in the table. The $\rho$ − t curves for both the tubes tested are similar, and in configuration resemble the $\rho - t$ curve for pure nickel [6]. Both curves show that $d\rho/dt$ decreases considerably after t = 350°C. Beyond this same temperature the temperature coefficients of the thermal conductivity and Lorentz number change. In the temperature range 20-350°C $\rho$ increases by a factor of 3.8, and in the range 350-500°C – by about 30%. In the temperature range 100-350°C $\lambda$ decreases by 27%, and L increases by 11%, while in the range 350-500°C $\lambda$ and L remain almost constant. The change in the temperature coefficients of $\rho$, $\lambda$, and L is associated with the fact that nickel loses its magnetic properties near 350°C.




Electrical resistivity, thermal conductivity, and Lorentz number for nickel at various temperatures: a and b) $\rho$, $\lambda$, L of the materials of tubes Nos. 1 and 2; c) for 99.94% nickel [7]

The values of the electrical resistivity of both tubes (see table) are almost identical; the maximum difference between them is 2% at some temperatures. These $\rho$ values also agree well with Thompson's data for 99.8% pure nickel [6]; in the range 20-200°C his data are approximately 5% lower than ours, while at 400°C the difference between his data and ours is less than 1%.

The thermal conductivity values for the tubes tested agree well with the data of [7] for 99.94% pure nickel. In the temperature range 200-500°C the difference between our data and those of [7] does not exceed 5% (see figure).

In the range 350-500°C the thermal conductivities and Lorentz numbers for both tubes agree very well – the discrepancy does not exceed 3%.

Table

Thermal Conductivity, Electrical Resistivity, and Lorentz Number for Thin-Walled Tubes

| t, °C | $\rho \cdot 10^8$ ohm · m | | $\lambda$, W/m³ · deg | | $L \cdot 10^8 v^2/deg^2$ | |
|---|---|---|---|---|---|---|
| | Tube no. | | | | | |
| | 1 | 2 | 1 | 2 | 1 | 2 |
| 20 | 7.90 | 8.08 | — | — | — | — |
| 50 | 9.30 | 9.36 | — | — | — | — |
| 100 | 11.50 | 11.60 | 87.3 | 74.3 | 2.69 | 2.31 |
| 150 | 14.16 | 14.11 | 82.8 | 72.6 | 2.77 | 2.42 |
| 200 | 17.24 | 17.29 | 77.4 | 69.5 | 2.82 | 2.54 |
| 225 | 18.71 | 18.70 | 75.1 | 69.0 | 2.85 | 2.59 |
| 250 | 20.70 | 20.54 | 72.8 | 67.5 | 2.88 | 2.65 |
| 275 | 22.50 | 22.51 | 70.4 | 66.0 | 2.90 | 2.71 |
| 300 | 24.70 | 24.74 | 68.0 | 64.4 | 2.93 | 2.78 |
| 325 | 27.19 | 26.91 | 66.0 | 62.9 | 3.00 | 2.83 |
| 350 | 28.88 | 29.18 | 64.3 | 61.5 | 2.98 | 2.88 |
| 375 | 30.51 | 30.75 | 63.3 | 61.4 | 2.98 | 2.91 |
| 400 | 31.84 | 32.01 | 63.0 | 61.2 | 2.98 | 2.91 |
| 425 | 32.69 | 32.70 | 63.0 | 61.5 | 2.95 | 2.88 |
| 450 | 33.63 | 33.23 | 63.0 | 61.8 | 2.93 | 2.84 |
| 475 | 34.57 | 33.98 | 63.2 | 62.1 | 2.92 | 2.82 |
| 500 | 35.36 | — | 63.4 | — | 2.90 | — |

## NOTATION

$\lambda$ – thermal conductivity; L – Lorentz number; $\rho$ – electrical resistivity; $l$ – current passing through specimen; V, $\Delta t$ – voltage drop and temperature difference in working part of specimen; $l$, S – half length and cross-sectional area of working part of specimen; $t_2$ – temperature of middle of specimen; $\varepsilon N^2$ – experimentally determined correction for heat transfer between lateral surface of specimen and walls of screened oven.

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Dzerzhinskii Heat Engineering Institute,
Moscow