EXPERIMENTAL RESEARCH TO DETERMINE THE EFFECTIVE THERMAL CONDUCTIVITIES OF A LAYER OF FURNACE CHARGE

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UDC 536.2.08

This article describes the results of experimental research on the effective thermal conductivities of a layer of furnace charge consisting of steel pellets, small cylinders, and pelletized iron ores at temperatures up to 800°C, obtained by a steady-state method in a plane layer.

The main problem of present-day operation is to determine the effective thermal conductivities (λ_{ef}) for a charge whose pieces are larger than 15 mm, and to determine the relationship between the magnitude of this conductivity and the temperature and dimensions of the pieces.

The effective thermal conductivities of the charge in [1] were found on a small apparatus. The magnitudes λ_{ef} for the various temperatures were found by means of plotting curves along the height of the layer and determining the temperature gradients in the different parts of the layer according to the angle of inclination of the tangents to the temperature curves. With this type of method considerable errors are possible.

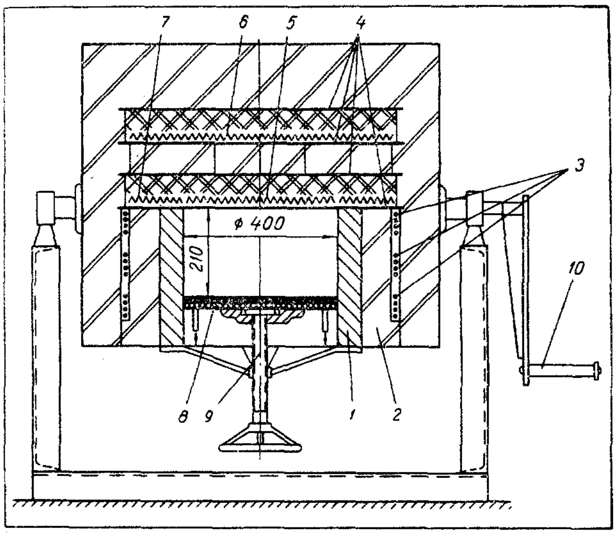

Fig. 1. Diagram of the experimental installation: 1) refractory tube; 2) lightweight refractory brick; 3) lateral compensation heaters; 4) sheets made from stainless steel; 5) central heater; 6) bottom compensation heater; 7) radial compensation heater; 8) cooler; 9) clamping screw, 10) hand lever.

Scientific-Research Institute of Thermal Techniques in Metallurgy, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 19, No. 1, pp. 42-46, July, 1972. Original article submitted September 10, 1969.

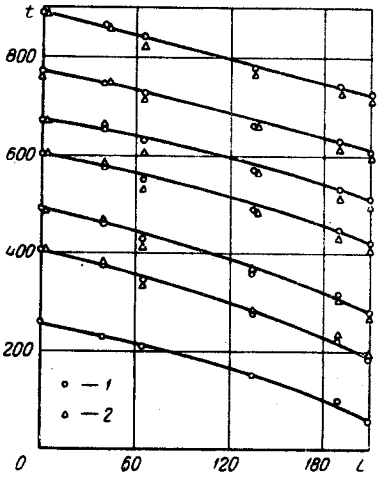

Fig. 2

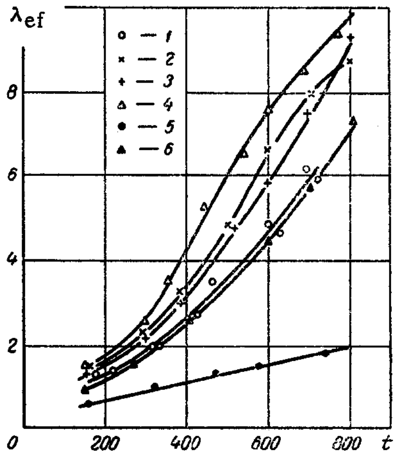

Fig. 3

Fig. 2. Variation of the temperature along the height of the layer of charge No. 3: 1) along the axis of the charge layer; 2) at 35 mm from the wall.

Fig. 3. Relationship between the effective thermal conductivities of the charges and the temperature (1-6, numbers of the charge): 1) 1, 2) 2, 3) 3, 4) 4, 5) 5, 6) 6.

We have chosen a steady-state method in a plane layer. A charge layer of cylindrical shape, diameter 400 mm height 210 mm, was investigated.

The general appearance of the apparatus is shown in Fig. 1.

In the apparatus compensation is provided for heat loss from the central heater in the bottom and radial directions and also in the radial direction along the height of the investigated charge layer.

The tests were carried out in steady conditions and the temperature drops in the layer did not exceed 240°C for the metallic charge and 385°C for iron ore pellets. The necessary temperature drop in the layer was reached by varying the thickness of the layer of insulation which was located between the charge and the cooler.

Five to eight basic experiments were carried out for each charge at different temperatures beginning with the lowest.

In addition, repeated experiments were made immediately after cooling of the apparatus without previous unloading of the charge. A total of 66 experiments was carried out, that is, an average of 11 experiments for each charge.

In order to avoid the influence of convection, the experiments were carried out with the thermal current directed downwards.

Initial heating and regulation of the steady-state system for the first temperature level was attained after 48-56 hours. An experiment was then carried out which took 1.5 to 2.0 hours, after which heating to the next temperature level was carried out for 24 to 40 hours, followed by another experiment, and so on.

The steady-state system was considered to have been attained if the temperature of the charge did not vary for 1.5 to 2.0 hours.

The characteristics of the investigated charges are given in Table 1.

The magnitudes of the thermal conductivities for the material of the steel charge in the range of temperatures observed in the experiments, can be considered as 25-50 W/m · deg.

The thermal conductivity of the material of calcined pelletized ores according to the investigations of S. G. Bratchikov [2] varies in the range 0.64 to 1.16 W/m · deg in a temperature range from 200 to 800°C.

TABLE 1

Charge No.	Material and shape of charge	Diameter of the piece $\cdot 10^2$, m	Length of the piece $\cdot 10^2$, m	Volume of the piece $\cdot 10^6$, m^3	Weight of the charge, kg	Porosity, %	Surface conditions
1	Charge 15 (spherical	1,91	—	3,64	122	40	Polished
2	The same	2,85	—	12,10	122	40	Unpolished
3	" "	2,84	—	12,00	122	40	Polished
4	" "	4,46	—	46,43	122	40	Polished
5	Iron ore pellets	1,74	—	2,75	56,4	37	Polished
6	Steel 3 (cylinders)	1,64	3,51	7,40	106	46	Unpolished

The magnitude of the effective thermal conductivity was calculated according to the formula

$$\lambda_{ef} = \frac{Ql}{F\Delta t}. \tag{1}$$

The thermal flux Q was determined by two methods: by measuring the discharge of heat from the central electric heater and from the quantity of heat determined from the heating of water in the cooler. In some experiments quite a large difference was obtained between these magnitudes. This difference is explained by loss of heat along the refractory tube 1 (Fig. 1). The average thermal flux calculated as the arithmetical mean between both measured flows was substituted into Equation (1). For all the charges besides the spherical charge No. 3 with d = 28.4 mm, the maximum difference between the average value and the measured values did not exceed 7.4% of its magnitude. For charges Nos. 5 and 6 (Table 1) it was less than 2.7-4.5%. For charge No. 3 this distance was higher in individual measurements.

Measurement of the temperature for all charges was carried out along the axis of the layer.

With a view to checking the temperature distribution along the horizontal cross section of the layer, experiments were carried out with measurement of the temperatures along the axis of the layer and at a distance of 35 mm from its edge. The results of the experiments are shown in Fig. 2, from which it is seen that there were no significant temperature drops over the cross sections. Temperature distribution curves along the height of the layer for steady-state systems are shown in this diagram for charge No. 3. Similar curves are obtained for the remaining charges. As is seen from the diagram, the distribution of temperatures along the height of the charge layer is close to linear, which gives a foundation for relating the obtained magnitudes of the thermal conductivities to the temperature of the layer calculated as the arithmetical mean between the temperatures on its edges.

Transfer of heat in the spaces between pieces of charge takes place by means of thermal conductivity, convection, and radiation. It is easy to ascertain by calculation that the part played by thermal conductivity at temperatures higher than 300°C is insignificant in comparison with radiation.

In the first place the direction of the thermal flux, from above to below or below to above, influences the magnitude of the convective heat transfer. In the first case the convective heat transfer will be negligible because in this case the density of the medium decreases in an upwards direction. This was the case in our main experiments and takes place in open-hearth furnaces and in a number of other thermotechnical units.

Experiments were carried out both with heating from above and with heating from below for the furnace charge No. 1. The magnitudes of the effective thermal conductivities obtained differed very little. Consequently the part played by convection in our experiments was small.

Observations of charges Nos. 1-4 showed that in the process of the experiment they were covered by a layer of scale 0.12-0.20 mm thick. Owing to this the area of contacts between the individual pieces increased, as a result of which in the repeated experiment the magnitudes λ_{ef} at low temperatures were obtained higher than in the original experiments. In the case of higher temperatures when radiation plays the main part in the heat transfer process, the layer of scale can serve as an obstacle to heat transfer. As a result of this in the repeated experiments at high temperatures lower values of λ_{ef} were obtained than in the original experiments.

In Fig. 3 is given a composite graph of the relationship between the effective thermal conductivity and the temperature for all the charges given in Table 1. It is seen from the diagram that for all metallic charges a rapid increase of λ_{ef} is observed with increase of the temperature in the layer. This indicates the important part played by radiation in the total heat exchange at high temperatures. Comparison between curve 2 and 3 for charges with polished spherical pieces and unpolished pieces and also comparison of the results in the case of the initial heating of a polished charge and repeated tests, indicate that the nature of the surface of the charge in our experiments does not play an essential part. This is explained by the fact that oxidation of the surface of the spherical pieces has already started at 300-400°C.

The charge which consists of cylindrical pieces has somewhat higher porosity than the charge composed of spherical pieces. Comparison of the magnitude λ_{ef} for this and for the charge with pieces of the same value shows that the charge composed of cylindrical pieces gives a magnitude of λ_{ef} which is 14-20% less than a charge composed of spherical pieces. This is probably explained by the poorer contacts between the pieces of the cylindrical charge and the presence of different kinds of shapes of pores.

The values λ_{ef} for pelletized ores which have a low thermal conductivity of the material differ both in their small magnitude in comparison with λ_{ef} for a metallic charge and by the nature of the relationship with the temperature. For pelletized ores a considerably lower increase of λ_{ef} with temperature increase is obtained than for metallic ores. This circumstance indicates that the influence of radiation on the heat exchange through the layer is considerably lower than in the case of a metallic charge, but the influence of the thermal conductivity of the material itself is greater.

NOTATION

λ_{ef}	effective thermal conductivity, W/m · deg;
Q	thermal flux, W;
l	thickness of the charge layer, m;
F	area of layer cross section, m^2;
Δt	temperature drop on the boundaries of the layer, deg;
d	diameter of the piece, m;
L	distance from the heater, mm.

LITERATURE CITED

1. B. L. Markov, and S. L. Solomentsev, Izv. Vuz. Chernaya Metallurgiya, No. 3 (1960).
2. S. D. Bratchikov, Izv. Vuz. Chernaya Metallurgiya, No. 6 (1961).