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Refractory materials — Determination of thermal conductivity —

Part 1:

Hot-wire methods (cross-array and resistance thermometer)

Matériaux réfractaires — Détermination de la conductivité thermique —

Partie 1: Méthodes du fil chaud («croisillon» et «thermomètre à résistance»)

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8894-1 was prepared by Technical Committee ISO/TC 33, *Refractories*.

This second edition cancels and replaces the first edition (ISO 8894-1:1987), which has been revised to include a hot-wire “resistance thermometer” method, as well as the hot-wire “cross-array” method and to harmonize the text with that of EN 993-14:1998, *Methods of testing dense shaped refractory products — Part 14: Determination of thermal conductivity by the hot-wire (cross-array) method*, prepared by CEN/TC 187.

ISO 8894 consists of the following parts, under the general title *Refractory materials — Determination of thermal conductivity*:

- *Part 1: Hot-wire methods (cross-array and resistance thermometer)*

- *Part 2: Hot-wire method (parallel)*

Refractory materials — Determination of thermal conductivity —

Part 1:
Hot-wire methods (cross-array and resistance thermometer)

1 Scope

This part of ISO 8894 describes the hot-wire methods ("cross-array" and "resistance thermometer") for the determination of the thermal conductivity of non-carbonaceous, dielectric refractory products and materials.

This methods are applicable to dense and insulating refractories (shaped products, refractory castables, plastic refractories, ramming mixes, powdered or granular materials) with thermal conductivity values less than 1,5 W/m·K ("cross-array") and less than 15 W/m·K ("resistance thermometer") and thermal diffusivity values less than 5×10^{-6} m^2/s.

Thermal conductivity values can be determined at a room temperature up to 1 250 °C. The maximum temperature (1 250 °C) can be reduced by the maximum service limit temperature of the refractory, or by the temperature at which the refractory is no longer dielectric.

NOTE 1 In general, it is difficult to make accurate measurements on anisotropic materials and the use of this method for such materials can be agreed between the parties concerned.

NOTE 2 The thermal conductivity of products with a hydraulic or chemical bond can be affected by the appreciable amount of water that is retained after hardening or setting and is released on firing. These materials might therefore require pre-treatment; the nature and extent of such pre-treatment and the period for which the test piece is held at the measurement temperature as a preliminary to carrying out the test, are details that are outside the scope of this part of ISO 8894 and are agreed between the parties concerned.

NOTE 3 The measurement of thermal conductivity is not sufficiently uncomplicated for an engineer to expect to achieve correct results without having particular work experience and if the work is based exclusively on this standard. Sufficient experience of measuring temperatures and laboratory skills are imperative.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
thermal conductivity

λ

density of heat flow rate divided by the temperature gradient

NOTE Thermal conductivity is expressed in watts per metre kelvin (W/m·K).

2.2
thermal diffusivity

a

thermal conductivity divided by the bulk density times the specific heat capacity

NOTE 1 $a = \lambda / \rho \cdot c_{\mathrm{p}}$

where:

λ is the thermal conductivity;

ρ is the bulk density;

c_p is the specific heat capacity at constant pressure per weight.

NOTE 2 Thermal diffusivity is expressed in units of square metres per second (m^2s^{-1}).

2.3
power
P
rate of energy transfer

NOTE Power is expressed in watts (W).

3 Principle

Both the hot-wire “cross-array” and “resistance thermometer” methods are dynamic measuring procedures based on the determination of the temperature increase against time of a linear heat source (hot wire) embedded between two test pieces which make up the test assembly.

The test assembly is heated in a furnace to a specified temperature and maintained at that temperature. Further local heating is provided by a linear electrical conductor (the hot wire) that is symmetrically embedded in the test assembly and carries an electrical current of known power that is constant in time and along the length of the test pieces.

The increase in temperature as a function of time follows a logarithmic law, and is measured and recorded from the moment the local heating current is switched on. The thermal conductivity of the test pieces is calculated using the rate of temperature increase and the power input.

For the “cross-array“ method, the temperature increase is measured using a thermocouple that is welded to the hot wire at its centre. The thermocouple leads are perpendicular to the hot wire.

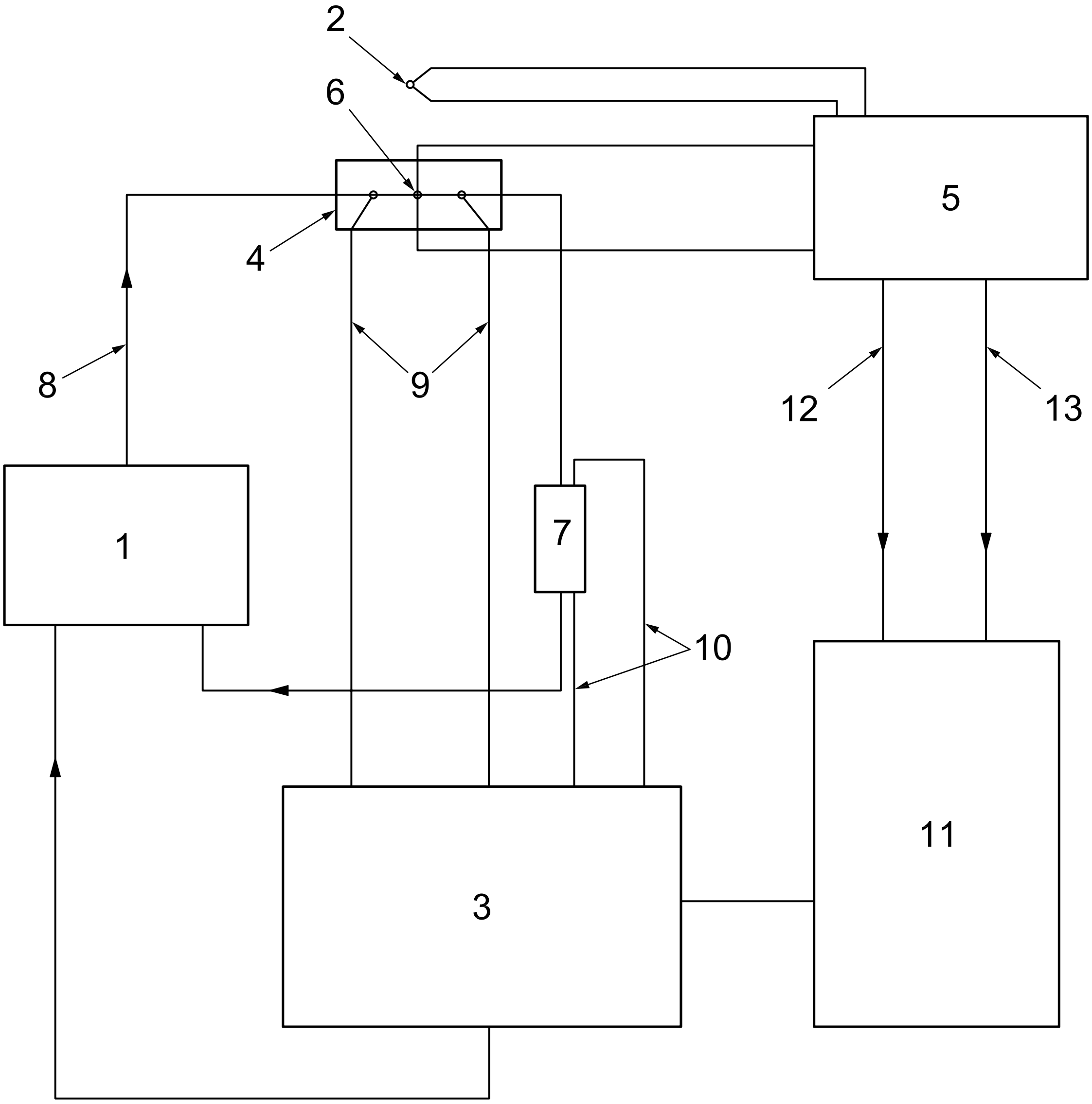
For the “resistance thermometer“ method, the temperature increase is measured by using the hot wire itself as both heat source and temperature sensor. An integral temperature measurement of the hot wire is carried out over the length between the voltage taps. The change in resistance of this part of the hot wire is determined. From these data, its temperature increase is calculated. The mathematical procedure is described in Annex A.

4 Apparatus

NOTE A block diagram of a suggested test apparatus for the “cross-array” method is shown in Figure 1 and for the “resistance thermometer” method in Figure 2.

4.1 Furnace, electrically heated, capable of taking one or more test assemblies (see 5.1) up to the required maximum test temperature. The temperature at any two points in the region occupied by the test pieces shall not differ by more than 10 K. The temperature measured on the outside of the test assembly during a test (of duration about 15 min) shall not vary by more than ±0,5 K, and shall be known with an accuracy of ±10 K.

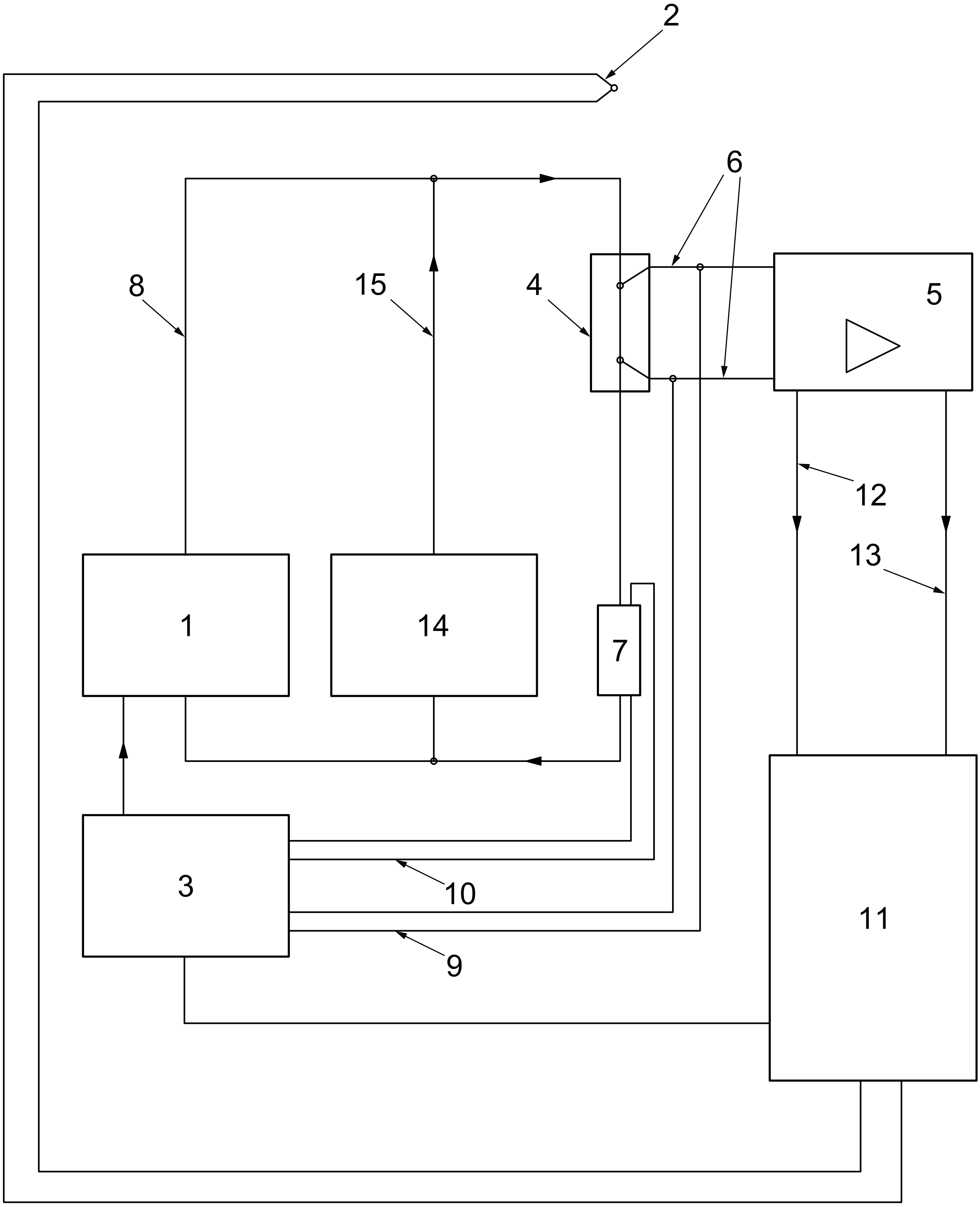
4.2 Hot wire, preferably of platinum or platinum-rhodium, with a minimum length equivalent to that of the test piece and a diameter not more than 0,5 mm. Both ends of the hot wire are attached to the power supply (4.4). Leads outside the assembly shall consist of two or more tightly twisted wires of 0,5 mm diameter. The current lead connections external to the furnace shall be made of heavy gauge cable.



Key

1 hot-wire power supply; a.c. source 1 kHz
2 reference thermocouple Tr
3 hot-wire power control unit
4 test assembly
5 cold junction of thermocouples
6 measurement thermocouple Ti
7 shunt
8 heating circuit
9 voltage taps
10 current measurement
11 data acquisition system and computer
12 absolute signal (Ti)
13 difference signal (Ti − Tr)

Figure 1 — Block diagram of apparatus for "cross-array" method



Key

1	hot-wire power supply; a.c. 1 kHz	9	a.c. voltage measurement
2	thermocouple	10	a.c. current measurement
3	hot-wire power control unit	11	data acquisition system and computer
4	test assembly	12	absolute signal R
5	amplifier	13	difference signal ΔR
6	voltage taps	14	d.c.source 100 mA
7	shunt	15	resistance measurement circuit
8	heating circuit		

Figure 2 — Block diagram of apparatus for “resistance thermometer” method

4.3 Voltage taps, made of the same material as the hot wire. The welded connections to the hot wire should be located in the test piece with a distance of about 200 mm, known to the nearest ±0,5 mm. The wires shall be of a diameter not greater than that of the hot wire. Both ends of the voltage taps are attached to the hot-wire power control unit (4.6).

4.4 Power supply, to the hot wire (4.2).

For the electrical heating of the hot wire during a single measurement (6.7) an adequate power supply is required.

4.4.1 For the "cross-array" method, the power supply shall be stabilized a.c. or d.c., but preferably a.c., and shall not vary in power by more than 2 % during the period of measurement. It shall be variable between 1 W/m and 20 W/m. This is equivalent to 0,2 W to 4 W between the voltage taps for a distance of 200 mm (see 6.5, Note).

4.4.2 For the "resistance thermometer" method, the power supply shall be stabilized a.c., and shall not vary in power by more than 2 % during the period of measurement. It shall be variable between 1 W/m and 125 W/m. This is equivalent to 0,2 W and 25 W between the voltage taps for a distance of 200 mm (see 6.5, Note).

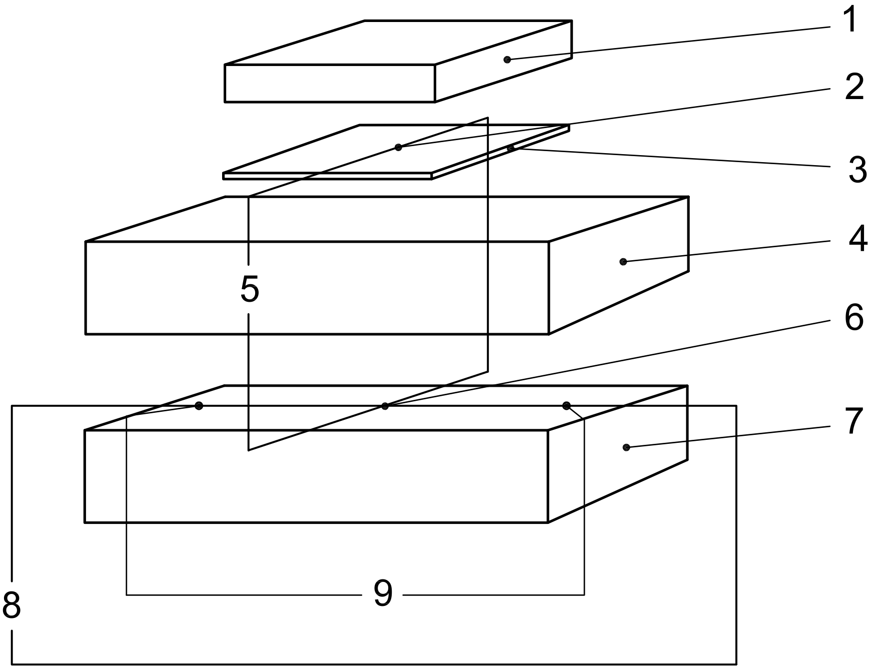
4.5 Equipment for the measurement of the temperature increase of the hot wire. The following arrangements for the "cross-array" and "resistance thermometer" methods shall be applied.

4.5.1 "Cross-array" method. For the "cross-array" method, use a differential platinum/platinum-rhodium thermocouple (Type S: platinum 10 % rhodium/platinum thermocouple or Type R: platinum 13 % rhodium/platinum thermocouple) formed from a measurement thermocouple (Ti) which is welded to the hot wire at its centre and a reference thermocouple (Tr) connected in opposition outside the furnace (see Figure 1). The leads of the measurement thermocouple shall run perpendicular to the hot wire. The output of the reference thermocouple shall be kept stable by placing it between the top outer face of the upper test piece and a cover of the same material as the test piece (see Figure 3). The maximum diameter of the measurement thermocouple wires shall not be greater than the diameter of the hot wire (to minimize loss of heat at the measuring point by conduction) and the wires of both thermocouples shall be long enough to extend outside the furnace where connections to the measuring apparatus shall be made by wire of a different type. The external connections of the thermocouple shall be isothermal. The measurement thermocouple (Ti) shall be used to indicate the temperature of the test assembly.

NOTE 1 An insulating layer can be inserted between the reference thermocouple and the upper test piece.

NOTE 2 For hot wire, voltage taps and thermocouples made of base metal can be used at temperatures below 1 000 °C.

NOTE 3 The reference thermocouple (Tr) can be replaced if a data acquisition system with an adequate resolution is used.



Key

1 cover

2 reference thermocouple Tr

3 optional insulating layer

4 test piece

5 differential measurement circuit

6 measurement thermocouple Ti

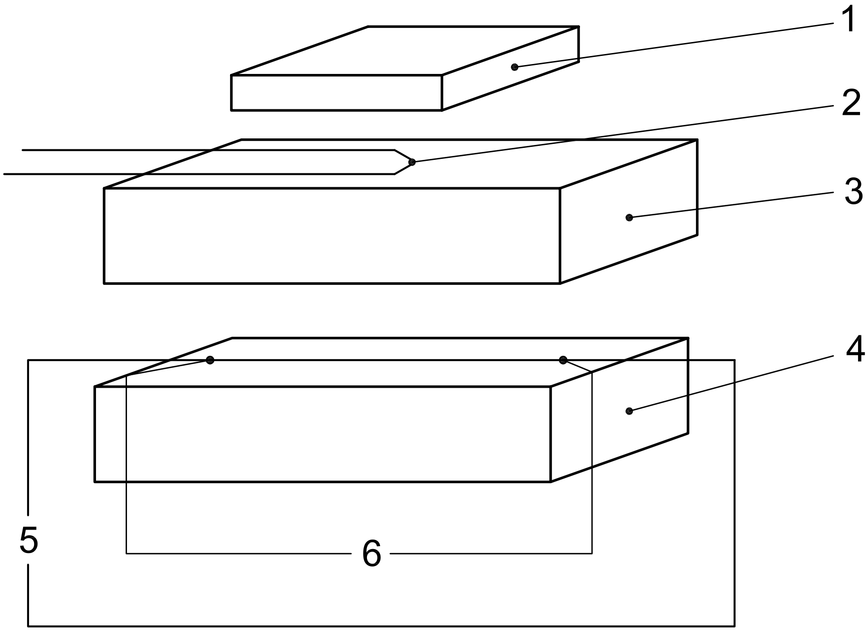
7 test piece

8 heating circuit

9 voltage taps

Figure 3 — Location of heating circuit and measurement circuit (differential thermocouple circuit) for "cross-array" method

4.5.2 "Resistance thermometer" method. For the "resistance thermometer" method, to measure the change in resistance of the hot wire, a low (e.g.100 mA) constant direct current (d.c.) is superimposed on the heating current (a.c.). The change of the d.c. voltage drop between the voltage taps is a measure for the change in temperature of the hot wire (see Figure 2). To indicate the temperature of the test assembly a separate thermocouple [e.g. the reference thermocouple (Tr)] shall be used (see 4.5.1). The arrangement of the hot wire and thermocouple is shown in Figure 4. As the hot-wire resistance during the measurement only changes within the range of parts per million (ppm) compared to its absolute resistance, a data acquisition system with an adequate resolution shall be used.



Key

1 cover
2 thermocouple
3 test piece
4 test piece
5 hot wire
6 voltage taps

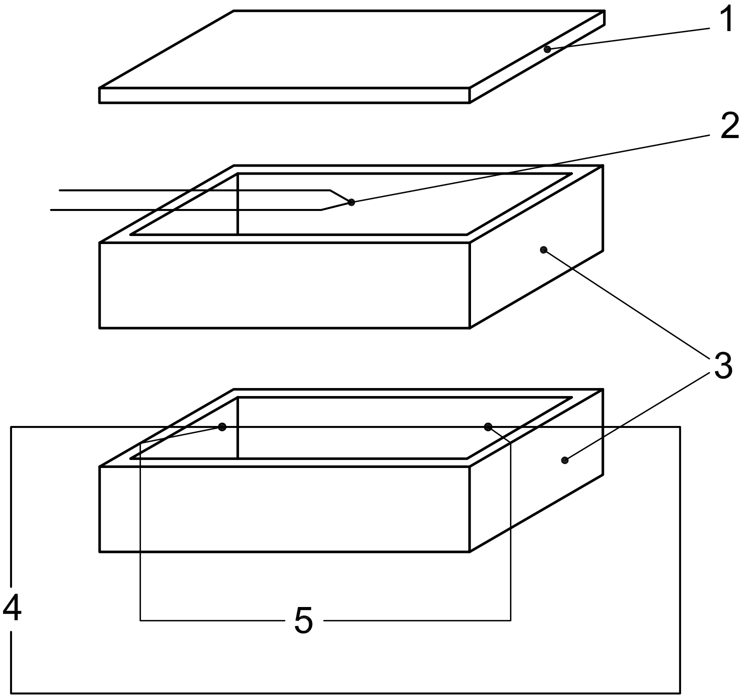
Figure 4 — Location of heating circuit and thermocouple for the “resistance thermometer” method

4.6 Hot-wire power control unit, or similar equipment, which may be combined with the constant power supply (4.4), used for measuring the current in the hot wire and the voltage drop across it, and capable of measuring both to an accuracy of at least ±0,5 %.

4.7 Data acquisition system, consisting of a temperature-time registration device with a sensitivity of at least 2 μV/cm or 0,05 μV/digit, or a temperature measurement of 0,01 K or better and with a time resolution better than 0,5 s.

4.8 Containers, for use if the test is performed on powdered or granular material, having internal dimensions equal to those of the solid test assembly specified in Clause 5, so that the test assembly shall consist of two test pieces as specified in 5.1. The bottom container shall have four sides and a base, and the top container shall have four sides only, plus a detachable cover (see Figure 5).

Containers should be of a material that will not react with the test piece at the test temperature and should not be electrically conducting.



Key

1 cover

2 thermocouple

3 containers

4 hot wire

5 voltage taps

Figure 5 — Container with hot wire and thermocouple laid on it — “Resistance thermometer” arrangement

5 Test pieces

5.1 Dimensions

Each test assembly shall consist of two identical test pieces, not less than 200 mm × 100 mm × 50 mm in size.

It is recommended that the size of each test piece be 230 mm × 114 mm × 64 mm, or 230 mm × 114 mm × 76 mm. Standard-size bricks can then be used as the test pieces forming the test assembly, subject to the requirements of 5.2.

5.2 Surface flatness

To guarantee a good thermal contact, the surfaces of the two test pieces forming the test assembly which are in contact with each other shall be flat. Grind them if necessary. The deviation from flatness between two points not less than 100 mm apart shall not be more than 0,1 mm. After the surfaces are ground, place the test pieces together to ensure that there is no noticeable rock or movement between them. Check for concave warping of the surfaces using a steel straight-edge.

5.3 Grooves in dense materials

In dense materials, grooves to accommodate both the hot wire and the measurement thermocouple (“cross-array” method), or the hot wire (“resistance thermometer” method) shall be machined in the upper (contact) face of the lower test piece of the test assembly (see Figure 6). The width and depth of the grooves shall permit the arrangement shown in Figure 6 to be achieved.

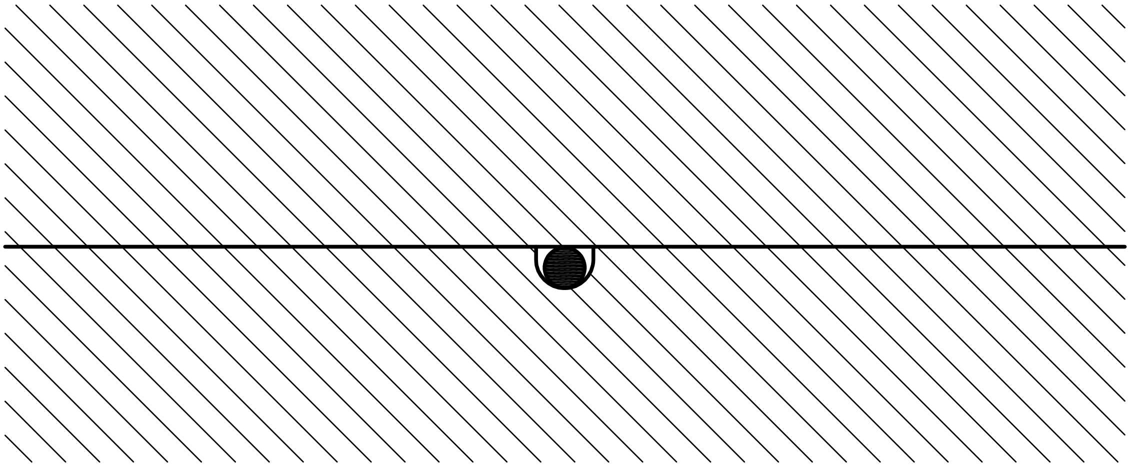


Figure 6 — Embedding of hot wire in test pieces (where required)

6 Procedure

6.1 Arrange the test assembly ready for testing. Place both the hot wire (4.2) and the measurement thermocouple (see 4.5) (“cross-array” method), or the hot wire (“resistance thermometer” method) between the two test pieces, with the hot wire along the centre-line of the brick faces in contact with each other. Cement them into the grooves where appropriate, using a cement made from finely ground test material mixed with a small amount of a suitable binder (e.g. 2 % dextrin and water). Ensure that the wires are cemented evenly, to allow equal heat transfer to the two test pieces, as shown in Figure 6.

6.2 If the test is being performed on powdered or granular material, fill the bottom container (4.8) with the test material up to its top, and place the hot wire and the measurement thermocouple (“cross-array” method), or the hot wire (“resistance thermometer” method) on it, as shown in Figure 4. Place the top container (4.8) on the bottom one and fill with the test material. Cover the test assembly with a slab of the same material as the containers. Determine the apparent bulk density of the test material in the poured, unstamped state.

NOTE The container can be filled by vibration or by pressing to give a specific bulk density, where a figure has been agreed upon.

6.3 Place the test assembly in the furnace (4.1), ensuring uniform heating by resting each assembly on two or three supports of a material similar to that being tested and having dimensions of 125 mm × 10 mm × 20 mm.

Rest the supports on a 125 mm × 10 mm face, and place them parallel to the end faces of the test pieces in such a position, to prevent a deformation of the test assembly during the test.

6.4 Connect the test assembly to the hot-wire power control unit (4.6), the hot-wire power supply (4.4), and the data acquisition system (4.7). Without a power supply to the hot-wire circuit, raise the temperature of the furnace, at not more than 10 K/min, to the first test temperature required. Test temperatures are not specified but should be agreed upon between the parties concerned and should be included in the report. Thermal conductivity values can be determined from room temperature up to 1 250 °C. The maximum temperature 1 250 °C may be reduced by the maximum service limit temperature of the refractory, or by the temperature at which the refractory is no longer dielectric.

Heating rates shall be low enough to ensure that there is no risk of thermal shock damage.

6.5 Set the power input to a value that will produce an increase in temperature of about 2 K to 5 K between the times t_1 and t_2 (see Clause 8, Note 1).

NOTE The level of the increase in temperature during the test is a function of the thermal conductivity of the material to be tested; the maximum test duration is a function of its thermal diffusivity.

The appropriate level of power input to the hot wire will differ between apparatus and depends on the sensitivity of the data acquisition system. A power input in watts per metre (Wm^{-1}) of about five times the expected λ-value of the material to be tested, will cause an increase in temperature of 1 K in one decade of the logarithmic time scaling in seconds (i.e. 1 s to 10 s; 10 s to 100 s; 100 s to 1 000 s).

Values for a typical test duration for the insulating material are between 600 s and 900 s.

6.6 When the furnace reaches the test temperature, verify that the temperature in the region occupied by the test assembly is uniform and constant, i.e.:

a) for the “cross-array” method, the differential thermocouple (see 4.5.1) does not show a variation of more than 0,05 K over a period of 15 min immediately prior to the test;

b) for the “resistance thermometer” method, the change in resistance of the hot wire does not show a variation which is equivalent to more than 0,05 K over a period of 15 min immediately prior to the test (4.5.2).

The equilibrium conditions shall not be more than 2 % of the expected increase in temperature between times t_1 and t_2.

6.7 When the conditions given in 6.6 are met, proceed as follows:

a) for the “cross-array” method, start the electrical power input to the hot wire and make a record of the output of the differential thermocouple with time, or

b) for the “resistance thermometer” method, measure and record the absolute resistance of the hot wire. Then start the a.c. power input to the hot wire and make a record of the change in resistance with time.

Mark the exact moment when the power input to the hot wire was made. Measure and record this input, immediately after switching on the heating circuit and again at intervals during the test period (see 6.5).

6.8 After the appropriate test duration, normally 10 min to 15 min, switch off the heating circuit and discontinue the recording of the output of the differential thermocouple for the “cross-array” method, or the change in resistance of the hot wire for the “resistance thermometer” method.

6.9 Allow time for the test assembly to reach the temperature equilibrium again. Repeat the measurement procedures given in 6.7 and 6.8, obtaining a further measurement under the same conditions.

6.10 Raise the temperature of the furnace to the next higher test temperature at not more than 10 K/min.

Repeat the procedure described in 6.5 to 6.9.

6.11 Repeat the procedure described in 6.10 until at least two and preferably three measurements have been obtained at each of the required test temperatures.

7 Assessment of results

If the power input to the hot wire has varied by more than 2 % during a test, disregard the results and perform the test again.

The recorded temperature rise, as a function of time, should produce a semi-logarithmic plot that is linear. If the plot is entirely non-linear, an operating error might have been made, so disregard the results and perform the test until a linear plot is achieved.

NOTE 1 If non-linear results persist after further testing, the material might not be suitable to fulfil the conditions of the test.

If the plot of temperature against time is non-linear at the lower end, this could be because of the influence of the embedding; i.e the bad thermal contact (resistance of heat transmission) between the hot wire and the surrounding material has the effect of a time delay.

NOTE 2 A valid result can possibly be obtained by choosing another value for t_1.

If the plot of temperature against time is non-linear at the upper end, this might be because of the thermal diffusivity of the material under test having a value that is too high.

NOTE 3 A valid result can be obtained by choosing another value for t_2.

8 Calculation and expression of results

Calculate the thermal conductivity, λ, of the material, in watts per metre kelvin ($\mathrm{Wm^{-1}K^{-1}}$), at each test temperature using Equation:

$$\lambda = \frac{P_\mathrm{i}}{4\pi} \cdot \frac{\ln(t_2/t_1)}{\Delta\theta_2 - \Delta\theta_1}$$

where:

P_i is the electrical power input per unit length to the hot wire, in watts per metre ($\mathrm{Wm^{-1}}$):

t_1 and t_2 are elapsed times, in seconds, after starting the power input to the hot wire;

$\Delta\theta_1$ and $\Delta\theta_2$ are the increases in temperature, in degrees Celsius (°C), after starting the power input to the hot wire at times t_1 and t_2.

NOTE 1 For insulating materials, typical times for t_1 are 100 s, and for t_2 600 s to 900 s

Report the result as the mean value of two tests at any one temperature.

The individual values of λ determined in each test should not deviate by more than 5 % from the mean value.

NOTE 2 Thermo-physical properties of refractory materials might change with the soaking time.

9 Precision

No precision data are currently available. Whilst it is possible to evaluate the error caused by the apparatus, the most serious error is caused by the sample preparation. This is not a statistical error which can be quantified.

10 Test report

The test report shall include the following information:

a) a reference to this International Standard, i.e. ISO 8894-1:2010;

b) all information necessary for identification of the material tested (including the manufacturer, product, type, batch number);

c) details of the procedure, including:

- the method used (“cross-array“ or “resistance thermometer“);

- any pre-treatment given to the test material (see Note 2 to Clause 1);
- in the case of powders or granular materials, the apparent bulk density in the poured, unstamped state (see 6.2);
- the furnace atmosphere;
- the test temperature or temperatures and, for each of them, the individual and mean values of thermal conductivity;
- the results of the test, including the results of the individual determinations and their mean, calculated in accordance with Clause 8;

d) the name of the test laboratory;

e) any deviations from the procedure specified;

f) any unusual features (anomalies) observed during the test;

g) the date of the test.

Annex A
(informative)

Data conversion of change in resistance to change in temperature

A.1 General

To compute the temperature increase of the hot wire from its change in resistance according to Equation (A.1), the coefficient $\beta(T) = \mathrm{d}R(T)/\mathrm{d}T$ as a function of temperature is required.

$$\Delta T = \frac{\Delta R}{\beta(T)} \tag{A.1}$$

where

ΔT is the temperature increase;

ΔR is the measured increase of resistance;

$\beta(T)$ is the slope of the function resistance/temperature at test temperature T.

A.2 Initial data

As the actual resistance $R(T)$ of the hot wire as a function of temperature is not known at the beginning of the first measurement, it has to be computed from theoretic specific resistance (ρ) data of the hot-wire material which are listed for Pt and Pt 90Rh10 in the following table:

Table A.1 — Theoretic specific resistance (ρ) data

Temperature °C	**Pt** Ω*mm^2/m	**Pt 90Rh10** Ω*mm^2/m
0	0,098	0,184
20	0,106	0,191
100	0,197	0,214
200	0,175	0,244
300	0,219	0,274
400	0,245	0,303
500	0,279	0,330
600	0,315	0,358
700	0,345	0,385
800	0,377	0,411
900	0,405	0,436
1 000	0,431	0,460
1 100	0,458	0,484
1 200	0,480	0,508
1 300	0,500	0,531
1 400	0,520	0,554
1 500	0,540	0,576

A.3 Approximation curve for the specific hot-wire resistance

A polynomial has to be created which goes through the data points taken from the table:

$$\rho_{\mathrm{p}}(T) = \sum_{k=0}^{n} a_k T^k \tag{A.2}$$

where

$\rho_{\mathrm{p}}(T)$ is the calculated specific hot-wire resistance as a function of temperature;

a_{k} are the polynominal coefficients;

T is the temperature.

The polynomial degree n (minimum 3) should not exceed a value which is greater than 1/2 the number of data pairs to avoid waves (in this case $\leqslant$ 8).

Determine the coefficients a_{k} of the polynomial using the condition of minimizing the sum σ of squares of deviations:

$$\sigma = \sum_{i=1}^{N} \left(\rho_{\mathrm{p}}(T_i) - \rho_i\right)^2 \tag{A.3}$$

where

σ is the sum of squares of deviation;

N is the number of data pairs (Table A.1);

$\rho_{\mathrm{p}}(T_i)$ is the specific resistance at temperature T_i, calculated according to A.2.

ρ_i is the theoretic specific resistance at temperature T_i (Table A.1);

T_i is the temperature at the i-th point.

A.4 Slope of the approximation curve

The resistance of the hot wire between the voltage taps as a function of temperature can be calculated as:

$$R(T) = \frac{l}{A} \rho_{\mathrm{p}}(T) \tag{A.4}$$

where

$R(T)$ is the calculated hot-wire resistance;

l is the distance between the voltage taps;

A is the cross-section of the hot wire;

$\rho_{\mathrm{p}}(T)$ is the calculated specific resistance at temperature.

The slope of the approximation curve (coefficient $\beta(T)$) can be described as follows (first derivation of Equation A.4):

$$\beta(T) = \frac{\mathrm{d}R(T)}{\mathrm{d}T} = \frac{l}{A}\sum_{k=1}^{n} a_k k T^{k-1} \tag{A.5}$$

The coefficient $\beta(T)$, as a function of temperature, depends on both the hot-wire diameter and the distance between the voltage taps. Because these parameters will change during the life of a hot wire, a relative temperature coefficient $\beta_\mathrm{r}(T)$, which is only specific to the hot-wire material itself, is defined as:

$$\beta_\mathrm{r}(T) = \frac{\beta(T)}{R(T)} = \frac{1}{\rho_\mathrm{p}(T)} \cdot \frac{\mathrm{d}\rho_\mathrm{p}(T)}{\mathrm{d}T} = \frac{\sum_{k=1}^{n} a_k k T^{k-1}}{\sum_{k=0}^{n} a_k T^k} \tag{A.6}$$

A.5 Slope of the relative approximation curve at the equilibrium temperature

To calculate the temperature increase from the change in resistance at equilibrium temperature, T_0, the slope of the relative approximation curve at this temperature is required. Calculate the corresponding value of the relative slope $\beta_\mathrm{r}(T_0)$ by Equation (A.7):

$$\beta_\mathrm{r}(T_0) = \frac{1}{\rho_\mathrm{p}(T_0)} \cdot \frac{\mathrm{d}\rho_\mathrm{p}(T_0)}{\mathrm{d}T} = \frac{\sum_{k=1}^{n} a_k k {T_0}^{k-1}}{\sum_{k=0}^{n} a_k {T_0}^k} \tag{A.7}$$

A.6 True temperature of the hot wire at which the measurement is carried out

The switching on of the hot-wire power may cause a jump of the temperature along the hot wire from the equilibrium temperature T_0 to a true temperature T_t with a jump of the resistance from R_0 to R_T (see Figures A.1 and A.2). This depends on the kind of embedding of the hot wire into the material to be tested (heat transmission resistance caused by a non-optimal contact between hot wire and test material) and the level of electrical power input to the hot wire.

Calculate the true temperature T_t with the actually measured corresponding resistances R_0 and R_T of the hot wire from Equation (A.8):

$$T_\mathrm{t} = T_0 + \frac{R_\mathrm{T} - R_0}{\beta_\mathrm{r}(T_0) \cdot R_0} \tag{A.8}$$

A.7 Slope of the relative approximation curve at the true temperature

Calculate the slope of the relative approximation curve at the true temperature T_t from Equation (A.9):

$$\beta_\mathrm{r}(T_\mathrm{t}) = \frac{1}{\rho_\mathrm{p}(T_\mathrm{t})} \cdot \frac{\mathrm{d}\rho_\mathrm{p}(T_\mathrm{t})}{\mathrm{d}T} = \frac{\sum_{k=1}^{n} a_k k {T_\mathrm{t}}^{k-1}}{\sum_{k=0}^{n} a_k {T_\mathrm{t}}^k} \tag{A.9}$$

A.8 Calculation of the temperature increase as a function of time

Taking Equation (1) with $\beta(T) = \beta_r(T)R_T$ (where R_T is the actually measured resistance at equilibrium temperature T_0 or at the temperature T_t) calculate the values for the temperature increase $\Delta T(t)$ during the measurement from the measured values of change in resistance $\Delta R(t)$ as follows:

a) if no jump of the temperature (see A.5) has been obtained:

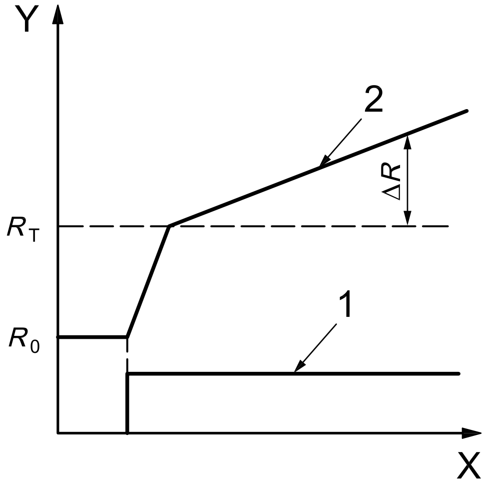
$$\Delta T(t) = \frac{\Delta R(t)}{\beta_r(T_0) \cdot R(T_0)} \tag{A.10}$$

b) if a jump of the temperature (see A.6 and A.7) has been obtained:

$$\Delta T(t) = \frac{\Delta R(t)}{\beta_r(T_t) \cdot R(T_t)} \tag{A.11}$$

A.9 Recalculation of the $\Delta T(t)$ data after a test run

To take into account a change in the behaviour of the electrical resistance with temperature of the hot wire by aging during the test, a recalculation of the $\Delta T(t)$ data should be carried out after finishing the test run, using the real electrical resistance values measured at each temperature step.

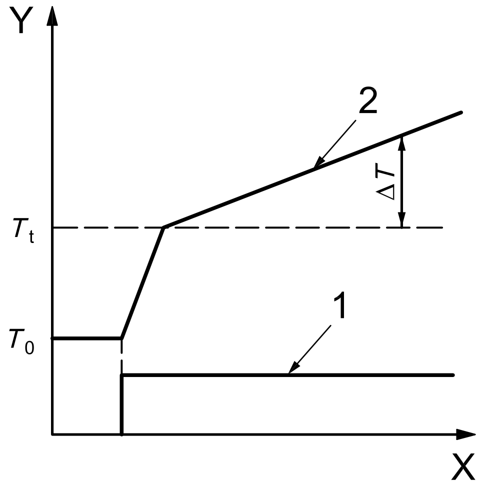


Key

X time

Y power (1) and resistance (2)

Figure A.1 — Resistance increase as a function of time



Key

X time

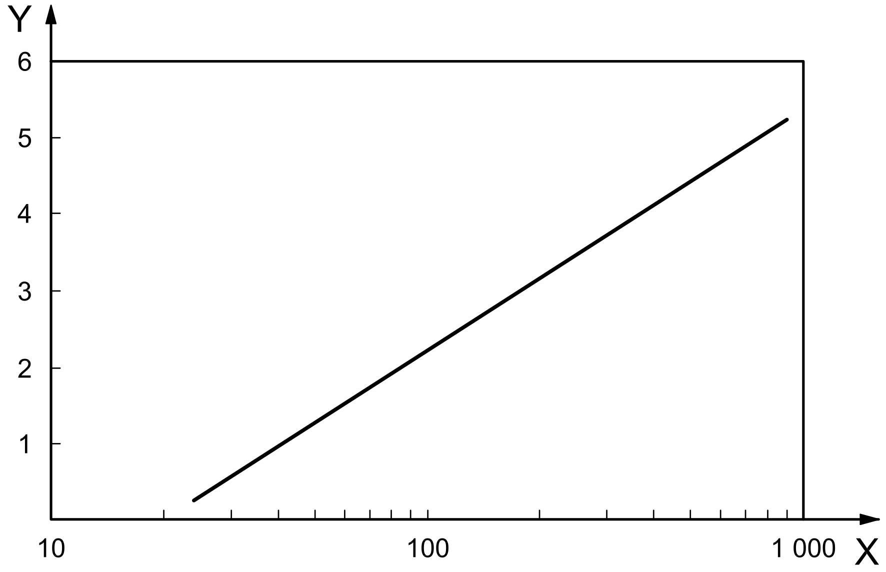
Y power (1) and temperature (2)

Figure A.2 — Temperature increase as a function of time

Annex B
(informative)

Examples of thermal conductivity measurements

An example of the graph of temperature against time for an insulating material of thermal conductivity $\lambda = 0,4$ W/m·K valid for both methods ("cross-array" and "resistance thermometer") is given in Figure B.1, and an example of the graph of temperature against time for a high alumina material of $\lambda = 15$ W/m·K for the "resistance thermometer" method is given in Figure B.2.



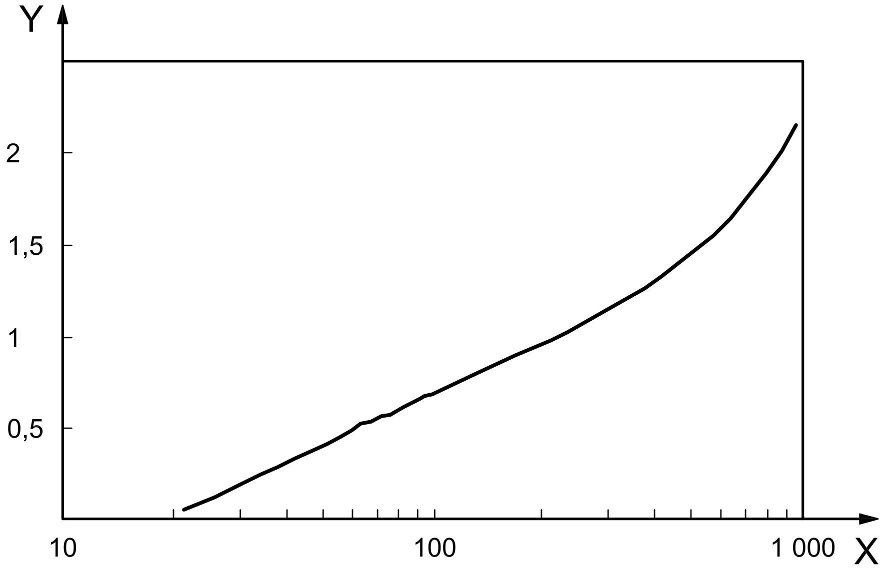
Key

X time, s

Y temperature, K

NOTE Due to the low thermal diffusivity of the material, a time value of 900 s could be taken for t_2.

Figure B.1 — Temperature/time graph for an insulating material ($\lambda = 0,4$ W/m·K) valid for both methods



Key

X time, s

Y temperature, K

NOTE Because of the high thermal diffusivity of the material the maximum time value for t_2 is 250 s.

Figure B.2 — Temperature/time graph for a high alumina material $\lambda = 15$ W/(m·K) **for the "resistance thermometer" method**

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