SELECTION OF THE STRUCTURES OF TUNNEL KILN SUSPENDED ROOF THERMAL INSULATION

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The pressing nature of the problem of improving the thermal insulation of tunnel kiln roofs is related both to the need for increasing the economy of this class of equipment and to requirements imposed by the production technology of modern types of refractories. Up to one-third of the heat provided to them is lost through the roof of high-temperature tunnel kilns [1]. An increase in the thermal resistance of the roof makes it possible to substantially reduce the specific fuel consumption for firing of parts. The production conditions of high-quality refractories, in particular those produced from materials based on pure oxides, require a quite long hold of the parts at high temperature, which is possible with good thermal insulation of the firing zone, dependent primarily upon thermal insulation of the roof.

The suspended roof design (Fig. 1), which has found wide use in tunnel kilns and to some extent in batch kilns, consists of the suspended parts 1 between which are fastened the intermediate bricks 2 with the help of a spline joint. The roof is thermally insulated by the packing 3 and the kaolin or slag wool 4. The material of the parts and the structure of the thermal insulation are varied over the length of the kiln in relation to the temperature level of the process. In the firing zone and adjoining positions of the heating and cooling zones of high-temperature tunnel kilns periclase-magnesite or corundum parts are used and the thermal insulation uses chrome-magnesite or corundum packing and kaolin wool. For the remainder of the kiln high alumina, chamotte, or dinas parts, chamotte packing, and kaolin or slag wool are used.

The temperature in the working space of the tunnel kiln determines the material of the parts used. The selection of the structure of the thermal insulation is dictated by the following considerations. The maximum temperatures of the thermal insulation material must not exceed the allowable limits of their service (for kaolin wool 1100°C and for slag wool 700°C) and the strength of the spline joint must provide reliable operation of the roof for a long time under service conditions, which is normally fulfilled if the temperature of at least one projection of each part does not exceed the temperature of the start of deformation under load T_{def} of the given material.

In addition, the type of steel used for production of the hook 5 must correspond to the temperature level at the point of its contact with the roof.

An increase in the thickness of the thermal insulation leads to a decrease in the heat flow through the roof but at the same time the roof temperature increases, as the result of which the above conditions may be violated. In connection with this, for each portion of the roof there exists an optimum structure of thermal insulation providing the least heat losses through the roof with maintenance of the conditions for its reliable service.

The temperature field of a roof element is described by the equation of steady thermal conductivity:
Fig. 1. Calculation element of the roof.

\[
\frac{\partial}{\partial x} \left( \lambda(T) \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( \lambda(T) \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( \lambda(T) \frac{\partial T}{\partial z} \right) = 0, \tag{1}
\]

where \( \lambda(T) \) is the thermal conductivity of the corresponding material in \( \text{W/(m}\cdot\text{K}) \), \( T \) is temperature in °C, and \( x, y, \) and \( z \) are the axes of the coordinates (Fig. 1).

The boundary conditions include:

the condition of equality of the lower surface of the roof to the temperature in the kiln \( T_k \)

\[
T = T_k \text{ at } z = 0; \tag{2}
\]

The condition of adiabaticity of the side surfaces of the calculation element of the roof:

\[
-\lambda(T) \frac{\partial T}{\partial n} \bigg|_b = 0; \tag{3}
\]

the condition of heat transfer of the outer surfaces of the roof into the surrounding medium:

\[
-\lambda(T) \frac{\partial T}{\partial n} \bigg|_b = \alpha(T_{\text{surf}}) \cdot (T |_b - T_{\text{surf}}), \tag{4}
\]

where \( n \) is the normal to the corresponding surface, \( \alpha \) is the total heat-transfer coefficient in \( \text{W/(m}^2\cdot\text{K}) \), \( T_{\text{surf}} \) is the average surface temperature in °C, and \( T_{\text{Surf}} \) is the temperature of the surrounding medium in °C. The subscript "b" refers the values to the boundary surfaces.

The thermal conductivities of the refractory and thermal insulation materials are described in the form [2]

\[
\lambda_i(T) = a_i + b_i T + c_i T^2 + d_i T^3 + e_i (T + 273)^{-1},
\]

where \( a_i, b_i, c_i, d_i, \) and \( e_i \) are constants for the given material (some of them may acquire zero values). The total heat-transfer coefficients of the outer surfaces include the convection and radiation components:

\[
\alpha(T_{\text{surf}}) = A(T_{\text{surf}} - T_{\text{surf}}) \sigma_o F \left[ \left( \frac{T_{\text{surf}} + 273}{100} \right)^4 - \left( \frac{T_{\text{Surf}} + 273}{100} \right)^4 \right],
\]

where \( A = 3.3 \) for horizontal surfaces facing upward and 2.6 for vertical [3], \( \sigma_o \) is the emissivity of an absolute blackbody and \( \sigma_o = 5.67 \text{ W/(m}^2\cdot\text{K}^4) \), \( \varepsilon \) is the degree of blackness of the material, and \( F \) is the slope.

The radiation component of the total heat-transfer coefficient takes into consideration the share of radiation of the given surface to the surrounding medium, which is characterized by the slope, which acquires for the different surfaces the following values: