

**SECTION 5. HEAT POWER ENGINEERING**DOI <https://doi.org/10.30525/978-9934-26-661-4-8>**ANALYTICAL STUDIES OF HEATING PROCESSES  
OF CERAMIC PRODUCTS****АНАЛІТИЧНІ ДОСЛІДЖЕННЯ ПРОЦЕСІВ НАГРІВАННЯ  
КЕРАМІЧНИХ ВИРОБІВ****Logvynenko D. M.**

*Candidate of Technical Sciences,  
Head of laboratory  
State Enterprise  
«All-Ukrainian State Research  
and Production Center  
for Standardization, Metrology,  
Certification and Consumers' Rights  
Protection»;  
Researcher  
The Gas Institute of the National  
Academy of Sciences of Ukraine  
Kyiv, Ukraine*

**Логвиненко Д. М.**

*кандидат технічних наук, начальник  
лабораторії  
Державне підприємство  
«Всеукраїнський державний науково-  
виробничий центр стандартизації,  
метрології, сертифікації та захисту  
прав споживачів»;  
науковий співробітник,  
Інститут газу Національної академії  
наук України  
м. Київ, Україна*

**Pylypenko R. A.**

*Candidate of Technical Sciences,  
Senior researcher,  
Leading researcher,  
The Gas Institute of the National  
Academy of Sciences of Ukraine  
Kyiv, Ukraine*

**Пилипенко Р. А.**

*кандидат технічних наук, старший  
науковий співробітник,  
провідний науковий співробітник,  
Інститут газу Національної академії  
наук України  
м. Київ, Україна*

One of the main tasks in the firing of ceramic products in tunnel kilns is the intensification of the heating process. The heating process is characterized by two main parameters: temperature and heating rate. The research was conducted to obtain a preliminary quantitative assessment of the heating process rate with subsequent experimental verification of the obtained data.

The analytical research was conducted on the example of bilateral symmetric heating of solid and hollow bricks with a linear change in temperature on the surface, which most closely corresponds to its heating in tunnel kilns.

Taking into account that the surface of the narrow faces of a standard single brick is 44% of its total surface, and up to 50% of the surface of the narrow faces in a conventional kiln cage is closed, for the calculation you can use the solution of the heat conductivity equation for heating an unlimited plate with a linear change in temperature on the surface [1, 2].

If we take into account that the heating of the brick in a tunnel kiln occurs in such a way that its speeds are set in certain temperature intervals based on permissible differences in thickness, then it is advisable to consider a multi-stage heating mode, in which the temperature change on the surface occurs along a broken line consisting of straight sections, especially since any temperature heating curve can be replaced by a broken one with straight sections.

The resulting solution of the heat conductivity equation with a linear change in temperature on the surface for multi-stage heating has the form

$$t = t_S + \frac{C_m \cdot S^2}{2a} \cdot \left( \frac{x^2}{S^2} - 1 \right) + \frac{S^2}{a} \cdot [C_1 \cdot \Phi^1 + (C_2 - C_1) \cdot \Phi^{11} + \dots + (C_m - C_{m-1}) \cdot \Phi^m] \quad (1)$$

where

$$t_S = C_1 \cdot \tau_1 + C_2 \cdot \tau_2 + \dots + C_m \cdot \left( \tau - \sum_{i=1}^{m-1} \tau_i \right)$$

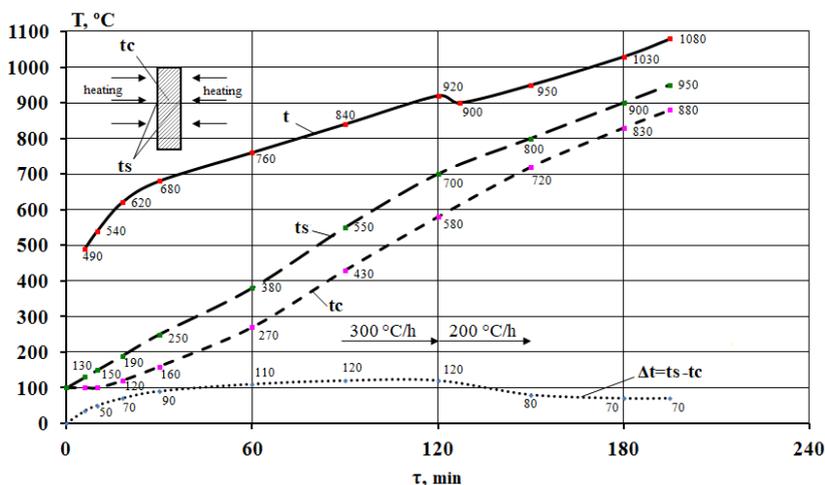
In solution (1) the number of terms included in the sum of an infinite series is equal to the number of heating stages. Each of the terms is the product of the differences in the heating rate in this and the previous sections and the function  $\Phi$ , which is determined by the dependencies for single-stage heating for the entire time from the beginning of this section [1].

The proposed solution allows you to determine the temperature field at any stage of heating, holding or cooling. In the specified solution, the thermophysical properties of the brick have constant values. The values of the thermal conductivity coefficient  $\lambda$ , thermal diffusivity  $a$  and heat capacity  $C_p$  change during heating. The reliability of the calculation increases with correctly selected average values of these coefficients in the temperature change interval. The true dependence of the thermal conductivity coefficient, thermal diffusivity and heat capacity of ceramic materials on temperature, taking into account endo- and exothermic reactions, is quite complex. To solve thermophysical problems, for the purpose of simplification, a rectilinear dependence of their values on temperature is usually assumed, and this coincides quite well with experimental data.

In the calculations, the average values of the thermal conductivity coefficient, thermal diffusivity and heat capacity were determined as the arithmetic mean of the extreme values in the temperature intervals studied.

Two-stage, speed-dependent heating of bricks was analyzed. In the first stage, the surface temperature of the wide faces varied from 100 °C (conditionally accepted for the end of brick drying in a tunnel kiln) to 700 °C, in the second stage – from 700 °C to the final firing temperature, which is 950 °C.

Fig. 1 shows a graph of the calculation of two-sided symmetrical heating of a solid brick measuring 250x120x65mm at some real heating rate values of 300 C/h and 200 C/h for heating clay bricks.



**Fig. 1 Two-sided symmetrical heating of a solid brick 65 mm thick with a linear change in surface temperature at a heating rate of 300 °C/h from 100 to 700 °C and at a rate of 200 °C/h from 700 to 950 °C**

The heating mode corresponds to the curve  $t_s$ . The curve  $t$  characterizes the temperature of the medium in the furnace. The estimated heating duration was 195 minutes, of which – 120 minutes at a rate of 300 °C/h from the initial temperature of 100 °C to the surface temperature of 700 °C, 75 minutes – at a rate of 200 °C/h in the range of brick heating temperatures of 700–950 °C, respectively. In this case, the final temperature of the medium in the furnace  $t$  was 1080 °C. At a heating rate of 300 °C/h, the maximum temperature difference between the surface and the middle section of the brick was 120 °C, and at a rate of 200 °C/h – 80 °C. The temperature difference between the surface and the center of the brick in Fig. 1 at the end of heating was 70 °C. This indicates the need for holding

at the end of each heating period to equalize the temperature throughout the thickness of the brick and relieve thermal stresses [3].

With a linear change in surface temperature and an unchanged average value of the thermal diffusivity coefficient, the temperature difference between the surface  $t_s$  and the middle  $t_c$  during heating increases until it reaches the largest value  $\Delta t_{\max}$ , which does not change further for values of the Fourier number  $Fo > 1$ . This maximum temperature difference is directly proportional to the heating rate, the square of the thickness and inversely proportional to the thermal diffusivity coefficient and is practically independent of the nature of the heating in the first stage [3]:

$$\Delta t_{\max} = \frac{C \cdot S^2}{2a} \quad (2)$$

The true temperature dependence of  $\lambda$ ,  $\alpha$ , and  $C_p$  of ceramic materials, taking into account endothermic and exothermic effects, is complex. For the sake of simplicity, a linear dependence of their values on temperature is usually adopted when solving thermophysical problems, which agrees reasonably well with experimental data. This solution assumes constant values for the thermophysical properties of the heated material.

The results of the analytical analysis lead to the need for development and development of individual designs of tunnel kilns for different types of clay slurry using the method of extracting the best product from the product.

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