Temperature field analysis of tunnel kiln for brick production

J. Duraković, S. Delalić

University of Zenica, Faculty of Metallurgy and Materials Science,
Travnicka cesta 1, 72000 Zenica, BiH;
E-mail: jusuf.durakovic@famm.unze.ba

Received: September 25, 2006 **Accepted**: November 14, 2006

Abstract: Today researches in the field of brick production mostly deal with problem of fuel consumption. Average specific fuel consumption in brick production lines is approximately 2100 kJ per 1kg of the product. Such values are in engineering praxis considering as very high.

Ovens in ceramics industry are optimized according to requested quality of products which ought to be made with minimal fuel consumption. This can be successfully achieved only if the burners are supplied with sufficient amount of energy and if energy of burned materials are connected or included into the process of increasing supplied energy thus affect the sintering curve.

This work is an approach of determination of temperature fields in tunnel kiln for brick production.

Keywords: Brick production, Tunnel kiln, Temperature field

Introduction

Uneven distribution of temperature through the sections of material layers, starting from the bottom then all over to the top of the kiln, is a very common occurrence in brick production.

Hence, row bricks material at the lower sections normally stay at lower temperature, while upper sections of materials do with sharp increasing temperature. Thus the temperature curves of raw materials in this temperature area show some differences. To some extent, equalizing of the temperature across the heigh of raw clay might be adequately done by using circulatory equipment. As a consequence, relatively significant differences in temperature field occur in that area, primarily due to the energy set up by fuel combustion. Top sections of clay are exposed to high temperature level for some time. Middle and lower sections are also subjected to sharp temperature increasing during the heating process. Process optimization described by mathematical model should offer reliable proof about parameters with strongest influence on desired values. Modeling is required for those parameters that significantly affect the production process. Others should be included by correlations[1-3].

Energy balance mostly consists of flue gas energy then, temperature of the product at the kiln exit, preheated air temperature, maximal temperature of sintering process, additional volume of air used as a heat transfer medium and possible volume of air pull out of the cooling area[4-6]. Heat transfer

Scientific paper

direction regarding the kilt conveyer direction of movement in tunnel kiln might be of less interest then the vertical heat transfer which forms mechanism of heat transfer by a lateral convection[7].

MATHEMATICAL MODEL

Fuel consumption by unit of a product in brick production considerably affects the price of a final product. Hence the final goal of any brick manufacturer is a production by optimal fuel consumption and at the same time with required and satisfactory quality of product. Thus the different approaches and possibilities of decreasing specific fuel consumption have been investigated.

For mathematical analysis of all significant parameters that affect the fuel consumption in tunnel kiln, it is necessary to define temperature field inside kiln. Main heat transportation medium in the kiln is fuel gas, so in order to get the relationship that define temperature field in kiln, current state and conditions inside it must be taken into consideration[8]. According to these conditions appropriate partial differential equation has to be set up. Modified partial differential equation that describes heat transfer is as follows[9]:

$$M \cdot \frac{\partial^2 U(x,y,z,t)}{\partial t^2} + H \cdot \frac{\partial U(x,y,z,t)}{\partial t} - K^2 \cdot \nabla^2 U(x,y,z,t) = F(x,y,z,t) \tag{1}$$

where are:

- M, mass of the medium,
- U, spatial coordinate and time dependent function connects physical meaning of parameters M, H, and K^2, and function F(x, y, z, t),
- H, heat transfer resistant factor or specific force that cause change in velocity of field U by time t,
- K, specific force that cause change in acceleration of field U by spatial variable Fexternal force cause changes in field state, and ∇^2U , Laplace's operator.

If M is too small comparing to H, and if field U is independent of time t, changing only when the spatial coordinates are changing, then finally if we assumed that area of interest for consideration is of quadrilateral shape and negligible comparing to overall length L of tunnel kiln, expression (1) became:

$$-K^2 \cdot \frac{\partial^2 U(x)}{\partial x^2} = F(x) \tag{2}$$

In this case U(x) means temperature and can be replaced by abbreviation for absolute temperature T(x). Boundary conditions are $U_{(0)}=u_0$, $U_{(L)}=u_L$.

Solution is obtained in three phases.
First, since the U(x) depends only of x coordinate, partial derivation can be expressed as a ordinary derivation:

$$\frac{d^2U(x)}{dx^2} = -\frac{F(x)}{K^2} \tag{3}$$

Which means that G(x) function whose second derivation is G"(x) have to be found by integration as follows:

$$G(x) = \int \left\{ \int \left[-\frac{F(x)}{K^2} \right] dx \right\} dx \tag{4}$$

Second, desire field function U(x) is obtained by equation (5):

$$U_{(x)} = G_{(x)} + A \cdot x + B \tag{5}$$

where A and B are the random constants.
A and B are defined according to boundary conditions of field function U(x), that are: $U_{(0)}=u_0$, $U_{(l)}=u_{L.}$

$$U(x) = G(x) + [uL - u0 - G(L) + G(0)] \cdot \frac{x}{L} + u0 - G(0) \tag{6}$$

If upon the temperature field acts external force F(x), it cause "echo", so the temperature field U(x) has obtained form. Function U(x) is echo function of temperature field equilibrium (the balance of thermal state of the system). Function U(x) is produced through the balance of external force F(x) and force that causes changes in U(x) field only when x variable is changing time independent. This working regime is characteristics for many heat aggregates. While keeping the temperature during the time, thermal aggregate is in state of equilibrium. This state became stationary after some time of oven heating. To determine real U(x) function all before mentioned parameters must be defined: the length L, then U_0 and $U_{L.}$.

The most important step is determination of parameter K– giving its value followed by dimension and unit. H function influence on equilibrium state might be negligible since it is assumed that U is time independent function, so it can be written that H = 1. Function F(x) depends of heat conducted into the kiln. The discretization above aimed to enable easier computer modeling and calculation, but also form step approximation of function F(x). Sense of the discretization is to replace all functions $F_{(t,T,x,y,z)}$ which depend of time, spatial coordinates and place inside the kiln, with set of discrete values.

Equilibrium function

Starting point is assumption that there exists a relationship between final product characteristics and factors such as: temperature field regime inside the kiln, refractory linings, carriage and product. This relationship is very complex by its nature (affected by nature of factors by itself as well as by number of different influencing factors). Manufacturing process essentially is a mechanism that realizes mentioned relationships in a way that each product is accompanied by values of certain campaign for which temperature equivalent of heating the chamber, that is actually fuel consumption per 1 kg of product, can be measured.

Temperature equilibrium data has been presented by measured heating curve (Figure 1) from which values of the coordinates x and

Table 1. Measuring points and temperatures in the chamber

T_1 (0.0 m, 30 ^{0}C)	T_2 (3.9 m, 65 ^{0}C)	T_3 (19.9 m, 400 ^{0}C)	T_4 (25.1 m, 440 ^{0}C)
T_5 (30.8 m, 460 ^{0}C)	T_6 (36.9 m, 600 ^{0}C)	T_7 (43.2 m, 710 ^{0}C)	T_8 (45.8 m, 780 ^{0}C)
T_9 (48.4 m, 825 ^{0}C)	T_{10} (51.0 m, 860 ^{0}C)	T_{11} (53.6 m, 865 ^{0}C)	T_{12} (56.2 m, 865 ^{0}C)
T_{13} (58.8 m, 865^{0}C)	T_{14} (61.4 m, 865 ^{0}C)	T_{15} (71.6 m, 800 ^{0}C)	T_{16} (82.6 m, 710 ^{0}C)
T_{17} (88.0 m, 660 ^{0}C)	T_{18} (118,0 m, 60 ^{0}C)		

Abbreviated as Ti ($de_{[i]}$, $ve_{[i]}$), i = 1,2,...,18.

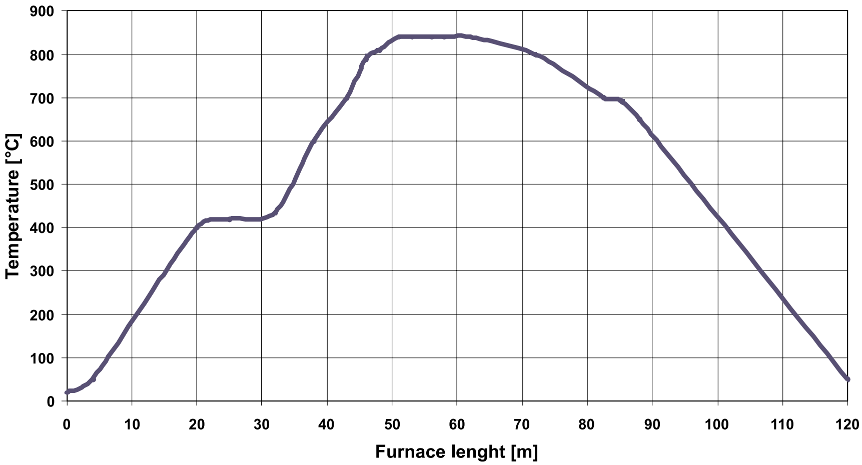

Figure 1. Measured heating curve

y were taken: x (distance from starting point or enter into the chamber) and y (temperature equivalent of the external force).

From the diagram in Figure 1, 18 points with their coordinates have been taken and separately presented in Table 1.

External force function is unknown since the K value is also unknown. But values of the temperature given in Figure 1 might be taken as a thermal energy equivalent used to obtained force F. Then, external force is presented as:

$$F_x = \begin{cases} V_{[i]} & if\ x = de_{[i]} \\ & \qquad i = 1,2,3.. \\ 0 & if\ x \neq de_{[i]} \end{cases} \qquad (7)$$

where is $V_{[i]} = ve_{[i]}/(K^2)$.

Desired function $G_{(x)}$ for which is $G_{(x)}=F_{(x)}$ or

$$G'(x) = \int_{de[i]}^{x} F(x)dx \quad . \qquad (8)$$

Integration results in:

$$G_{'(x)} = V_{[i]} \quad \text{for } de_{[i]} \le x \le de_{[i+1]}, \quad i = 1,2,3.... \qquad (9)$$

And finally:

$$Gi_{(x)} = ci \cdot x + ci, \text{ for } de_{[i]} \le x \le de_{[i+1]}, \ i = 1,2,3 \qquad (10)$$

Function of the temperature field is expressed as:

$$T_{(x)} = Gi_{(x)} + c_{i1} \cdot x + c_{i2}, \text{ for } de_{[i]} \le x \le de_{[i+1]}, \ i = 1,2,3.... \qquad (11)$$

Following conditions must be fulfilled:

$$T(de_{[i]}) = V_{[i]}, \qquad i = 1,2,3.... \tag{12}$$

and:

$$Gi(de_{[i]}) = g(i) = g = g_{(i+1)} = Gi(de_{[i+1]}), \qquad i = 1,2,3.... \tag{13}$$

And the last step is to obtain values for $T_{(x)}$:

$$T_{(x)} = V_{[i]} + \frac{(V[i+1] - V[i])}{(de[i+1] - de[i])} \cdot (x - de[i]) \tag{14}$$

It is clear that $T(de_{[i]}) = V_{[i]}$ i $T(de_{[i+1]}) = V_{[i+1]}$, for i = 1,2,3....

Equation (14) describes the function of temperature equilibrium and thus the temperature field in a chamber after longer heating process.

The way in which temperature field in chamber has been generated, is shown in Figure 2. Computer program was developed on Delphi 3 programming language base at Faculty of Metallurgy and Materials Science, University of Zenica.

Results

For the determination of temperature field inside the kiln chamber it is common to use term "temperature equivalent of heat"[10]. Then, in initial Equation (1) instead of temperature, the heat that can be expressed by temperature, mass and specific heat, was included. This explain the reasons for usage of the temperature as a heat equivalent. Area closed by temperature curve and horizontal axis (Figure 2) represents the total heat necessary for achieving requested temperature

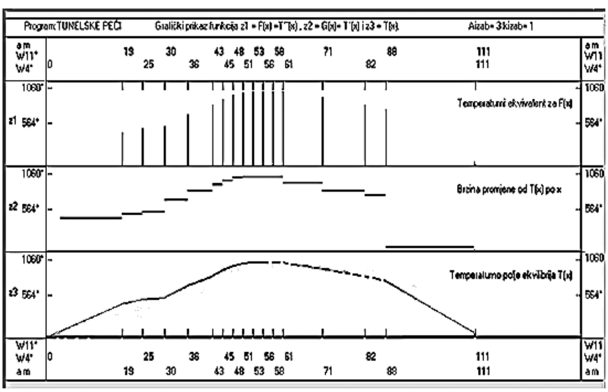

Figure 2. Temperature field output - testing case

inside the kiln. This enables determination of temperature equivalents in kiln as well as heat capacity.

The diagram (Figure 2) consists of three parts. Third part (Z_3) illustrates T(x) function. It is clear that this part match completely to the curve which is used for determination of T(x) function (Figure 1). This verify that temperature field inside the kiln can be obtained theoretically.

First part of the diagram (Z_1) represents temperature equivalent of the external force which is calculating according to expression $F(x) = T''(x)$. Finally, the second part of the diagram (Z_2) shows the rate of temperature change T(x) if x coordinate is changing. Function $G'(x) = T'(x)$ is also presented on this part of diagram.

Conclusions

In our work presented and discussed mathematical model is appropriate for analysis and checking of a stationary temperature field in brick products and in the furnace. Using developed software, it is possible to execute a simulation of temperature distribution in furnace during a brick production process in real conditions.

References

[1] L. M. Farg: Evaluation and optimization of an Egyptian tunnel kiln, Ziegelindustrie International, 9/2003.

[2] W. Hoffmann: Mathematische Grundlagen und Modellierung, Keramische Zeitschrift, 54/2003.

[3] H. Schmidt: Maβnahmen zur Begegnung von Schadesbildungen an Ziegeln beim Bremen, Ziegelindustrie International, 33/1991.

[4] W. Leisenberg: Reduzierung des Gesamtwearmeverbrauches im Ziegelwerk durch Mabnahmen am Ofen, Keramische Zeitschrift, 11/1985

[5] F. Pavlin, B. Kosec, M. Bizjak, M.C. Ferfolja: Temperature Profil Measurements in Wellman Type Annealing Furnaces, RMZ – Materials and Geoenvironment, 46 (1999) 1, 86 – 87.

[6] R. Jeschar, H.G. Bitner: Possibilities for the optimization of tunnel kiln processes in the brick and tile industry Quality improvement and reduction in energy consumption, Ziegelindustrie International, 10/1989.

[7] R. Jeschar, H.G. Bittner: A Mathematical Model for Layout and Optimization of Tunnel Furnace Processes in the Field of Ceramic Industry, 12th IMACS World Congress on Scientific Computation,Conference proceedings, 1988

[8] Y.V. Deshmulh: Industrial Heating, Taylor & Francis, Boca Raton, 2005.

[9] R. Jeschar, K. Junge: Heat transfer in counter-flow kilns, Gas Wearme International, 5/1980.

[10] L. Michalski, K. Eckersdorf, I. McGhee: Temperature Measurement, John Wiley &Sons, Chichester, 1991.