

Possibilities to Manage Burning Process at the Conditions of Cement Kiln

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Abstract - In the work are shown results of numerical modeling of burning process in the combustion chamber of cement kiln. A program for numerical modeling in the MATLAB platform, created in Faculty of Engineering and Pedagogy Sliven at Technical University Sofia is used. Received results show different ways to change the shape, position of the torch and temperature level in the combustion chamber.

Key words – numerical modeling, degree of rotation, gas fuel

I. INTRODUCTION

Rotary kiln is one of the most important units in the technological process for obtaining of clinker in the cement industry. It is got by firing to the boundary of melting of the finely ground particles and completely mixed raw materials taken in appropriate proportions. Firing takes place at about 1400 °C to convert into a solid product.

In these kilns is organized diffusion torch over a moving composite material. Its geometric shape and heat-exchange performance have to ensure optimal temperature regime in different zones, thermal efficiency and operating reliability of the furnace [1].

The raw material is given in the form of well-prepared sludge. Humidity of the sludge is in the limits 30-40%. Falling in the rotating kiln, the raw material consequently passes through different zones of physical-chemical conversion [2].

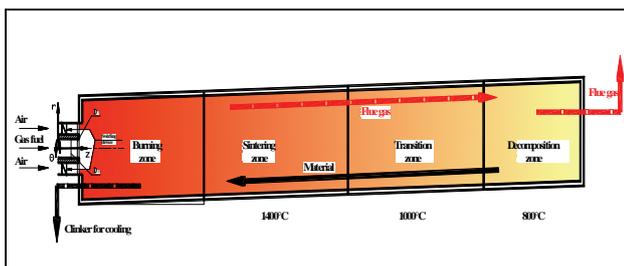


Fig. 1. Rotary furnace scheme of cement clinker formation.

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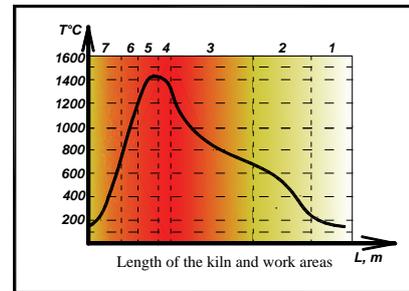


Fig. 2 Specific temperature zones.

Specific temperature zones along the furnace are following:

- 1 – drying zone (20%L);
- 2 – initial heating zone (25%L);
- 3 – zone of calcination (35%L) – dehydration and dissociation of carbonates;
- 4 – zone of exothermic reactions (5%L). - formation of silicates and compounds of aluminum and calcium;
- 5 – sintering zone (8%L);
- 6 и 7 – zones of cooling of the material (7%L) where, the combustion air simultaneously is heated to 250-300 °C (≈500K).

To create optimal technological regimes, well-grounded from economical point of view, is necessary to predict opportunities for active influence on combustion process in rotating furnace, allowing temperature changes along its length [3].

The purpose of this work is with numerical simulation of burning process in diffusion torch to obtain temperature regimes along the furnace.

The obtained results would be allowed to analyze the temperature conditions in the combustion chamber for appropriate management of the combustion process at constant heat load.

In numerical experiments are used geometric dimensions and thermal load of a real cement kiln. The main dimensions are:

- Diameter of the gas hole $D_{11} = 60$ mm;
- Diameter of the air hole $D_7 = 316$ mm;
- Diameter of the combustion chamber $D_5 = D_3 = 3000$ mm;
- Length of the burner $L_{75} = 1400$ mm;
- Length of the combustion chamber $L_{54} = 30000$ mm.

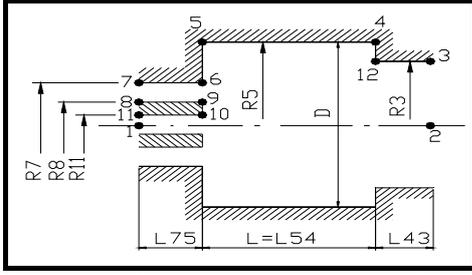


Fig. 3 Computational scheme of the combustion chamber with typical geometric dimensions.

The combustion process is simulated by fuel - natural gas, with a coefficient of excess air $\alpha = 1,05$ and temperature of air heating - 300°C .

On the basis of passport data is set nominal heat load at gas velocity - 120 m/s and air velocity - $86,5\text{ m/s}$ (300°C) and $45,27\text{ m/s}$ (20°C) according with dimensions of the geometric model.

The study is done at adiabatic conditions. In the different experiments is changed only the degree of rotation, determined by [4] in the range from 0 to 2,0, which corresponds to the possibilities of the swirling device of the burner.

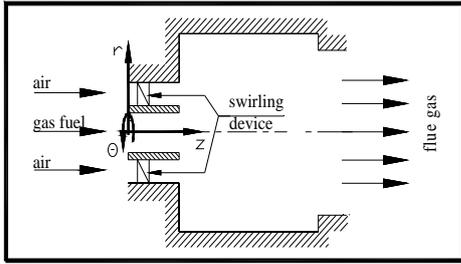


Fig. 4. Scheme of the combustion chamber with swirling device.

As a measure to define the degree of rotation of the jets is used the relationship: $s = \frac{\bar{w}}{\bar{u}}$, where \bar{w} and \bar{u} are average integrated values of tangential and axial components of the velocity vector.

II. NUMERICAL MODEL - FEATURES

The mathematical model is presented with a system of equations for the cylindrical coordinate system [5] and it is built on the basis of equations for the quantity of the motion, for energy and mass saving, and relationships describing the turbulent model, chemical reactions, boundary conditions, thermodynamic, the source and transmission properties of the fluid. The authors are used the JB Spalding's algorithm from London University, as the mathematical model is modified for non-isometric conditions. The differential equations are transformed into cylindrical coordinates.

They are as follows:

- Equation about velocity vortex:

$$r^2 \cdot \left\{ \frac{\partial}{\partial z} \left(\frac{\Omega}{r} \cdot \frac{\partial \psi}{\partial r} \right) - \frac{\partial}{\partial r} \left(\frac{\Omega}{r} \cdot \frac{\partial \psi}{\partial z} \right) \right\} - \frac{\partial}{\partial z} \left\{ r^3 \cdot \frac{\partial}{\partial z} \left(\mu_{\text{ef}} \cdot \frac{\Omega}{r} \right) \right\} - \frac{\partial}{\partial r} \left\{ r^3 \cdot \frac{\partial}{\partial r} \left(\mu_{\text{ef}} \cdot \frac{\Omega}{r} \right) \right\} - r \cdot \frac{\partial}{\partial z} (\rho \cdot w^2) - r \cdot \frac{\partial}{\partial z} \left(\frac{u^2 + v^2}{2} \right) \cdot \frac{\partial \rho}{\partial r} + r^2 \cdot \frac{\partial}{\partial r} \left(\frac{u^2 + v^2}{2} \right) \cdot \frac{\partial \rho}{\partial z} = 0 \quad (1)$$

- Burning equation:

$$\frac{\partial}{\partial z} \left(\varphi_{20} \cdot \frac{\partial \psi}{\partial r} \right) - \frac{\partial}{\partial r} \left(\varphi_{20} \cdot \frac{\partial \psi}{\partial z} \right) - \frac{\partial}{\partial z} \left(\frac{\mu_{\text{ef}}}{\text{Pr}} \cdot r \cdot \frac{\partial \varphi_{20}}{\partial z} \right) - \frac{\partial}{\partial r} \left(\frac{\mu_{\text{ef}}}{\text{Pr}} \cdot r \cdot \frac{\partial \varphi_{20}}{\partial r} \right) = 0 \quad (2)$$

- Equation for saving of the quantity of the motion on the direction Θ :

$$\frac{\partial}{\partial z} \left(r \cdot w \cdot \frac{\partial \psi}{\partial r} \right) - \frac{\partial}{\partial r} \left(r \cdot w \cdot \frac{\partial \psi}{\partial z} \right) - \frac{\partial}{\partial z} \left\{ r^3 \cdot \mu_{\text{ef}} \cdot \frac{\partial}{\partial z} \left(\frac{w}{r} \right) \right\} - \frac{\partial}{\partial r} \left\{ r^3 \cdot \mu_{\text{ef}} \cdot \frac{\partial}{\partial r} \left(\frac{w}{r} \right) \right\} = 0 \quad (3)$$

The differential equations in the numerical procedure for convenience are represented by general characteristic equation of elliptic type:

$$a_\varphi \cdot \left\{ \frac{\partial}{\partial z} \left(\varphi \cdot \frac{\partial \psi}{\partial r} \right) - \frac{\partial}{\partial r} \left(\varphi \cdot \frac{\partial \psi}{\partial z} \right) \right\} - \frac{\partial}{\partial z} \left\{ b_\varphi \cdot r \cdot \frac{\partial (c_\varphi \cdot \varphi)}{\partial z} \right\} - \frac{\partial}{\partial r} \left\{ b_\varphi \cdot r \cdot \frac{\partial (c_\varphi \cdot \varphi)}{\partial r} \right\} + r \cdot d_\varphi = 0 \quad (4)$$

The coefficients of the general characteristic equation are given in Table 1. By substituting the coefficients from the table in the general elliptic equation are obtained, the above differential equations.

Table 1 Coefficients of the characteristic equation.

φ	$a\varphi$	$b\varphi$	$c\varphi$	$d\varphi$
ψ	0	$\frac{1}{\rho \cdot r^2}$	1	$-\frac{\Omega}{r}$
$\frac{\Omega}{r}$	r^2	r^2	μ_{ef}	$-\frac{\partial}{\partial z} (\rho \cdot w^2) - r \cdot \left[\frac{\partial}{\partial z} \left(\frac{u^2 + v^2}{2} \right) \frac{\partial \rho}{\partial r} - \frac{\partial}{\partial r} \left(\frac{u^2 + v^2}{2} \right) \frac{\partial \rho}{\partial z} \right]$
$r \cdot w$	1	$\mu_{\text{ef}} \cdot r^2$	$\frac{1}{r^2}$	0
φ_{ro}	1	$\frac{\mu_{\text{ef}}}{\text{Pr}}$	1	0

In the program is introduced turbulent viscosity [7], based on the hypothesis of Kolmogorov-Prandtl for "way of mixing":

$$\mu_{\text{ef}} = K \cdot D^{\frac{2}{3}} \cdot L^{\frac{1}{3}} \cdot \rho^{\frac{2}{3}} \cdot (G_f \cdot V_f^2 - G_a \cdot V_a^2) \quad (1)$$

where: K is constant;

D and L dimensions of the combustion chamber;

G – mass flow;

Indexes f и a regarding fuel and air;

V_f и V_a are real velocity.

V_a in the calculation procedure is presented as a geometric sum of axial and tangential component of absolute velocity.

III. NUMERICAL STUDY

The main series of experiments are done at a temperature of air heating - 300 ° C (573.15 K).

An experiment without air heating - 20 ° C (\approx 300K) was carried out. For contrast reflecting of the ability to control the combustion process by changing the parameter - degree rotation of the flow, the regime conditions are same.

They include - thermal load, heat exchange with the environment, coefficient of excess air.

Results of the detailed study in the range of variation of the degree of rotation are shown in figures 5, 6 and 7.

They are charts of the vortex lines or contours, where the mass flow is constant in the half of the combustion chamber.

X axis is axial direction of the combustion chamber and Y axis is radial direction.

The units on both axes are number of integration steps.

The size of the integration steps are: axis z - $d_z = 250\text{mm}$, and axis r - $d_r = 15\text{mm}$.

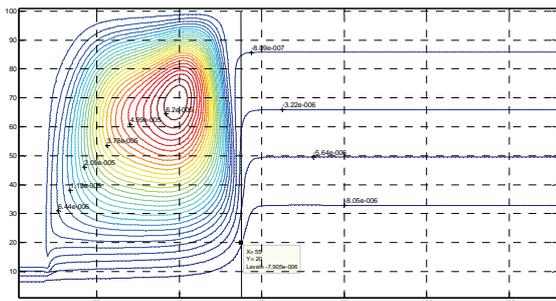


Fig. 5a Contours of the function ψ at $S=0$

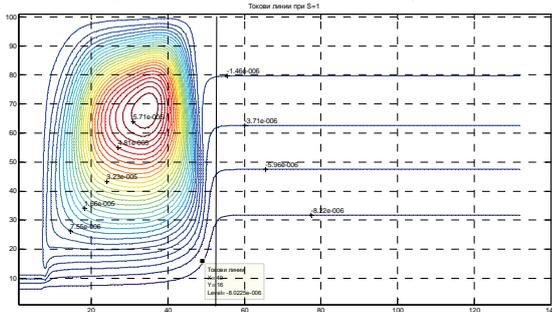


Fig. 5b Contours of the function ψ at $S=1$

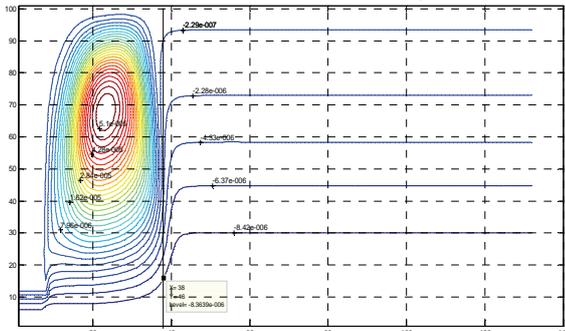


Fig. 5c Contours of the function ψ at $S=2$

Temperature fields in the combustion chamber at various cases of rotation of the burning gas torch are also displayed.

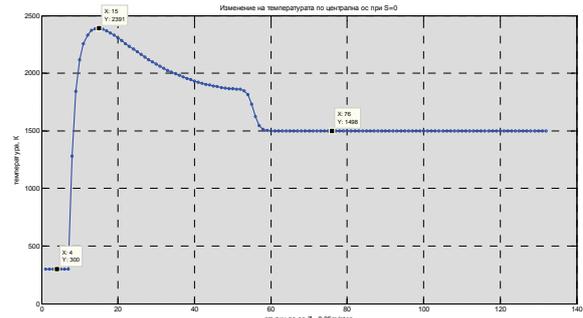


Fig. 6a. A temperature change in the central axis of the combustion chamber at $S=0$.

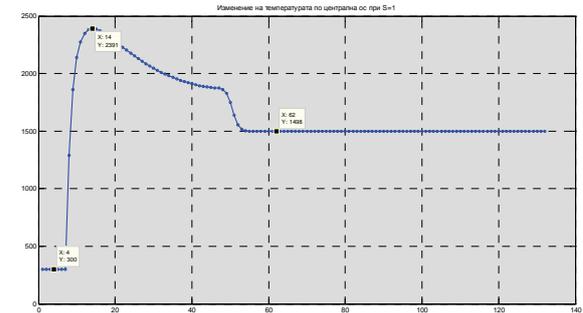


Fig. 6b. A temperature change in the central axis of the combustion chamber at $S=1$.

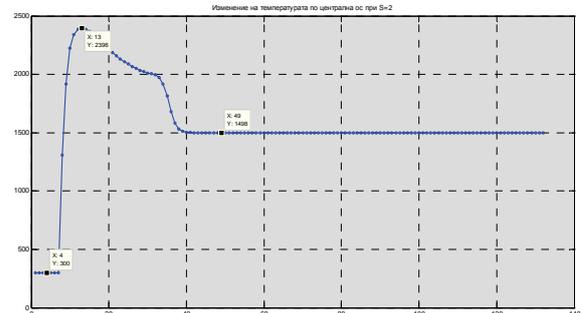


Fig. 6c. A temperature change in the central axis of the combustion chamber at $S=2$.

The following figures show us the distribution of isothermal surfaces in longitudinal section of the half of the combustion chamber.

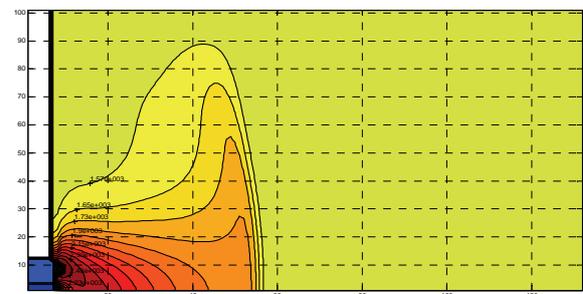


Fig. 7a Contours of the temperature change along the length of the combustion chamber at $S=0$, $T_a=573,15\text{K}$.

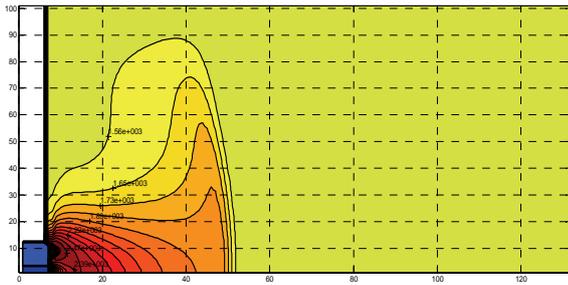


Fig. 7b Contours of the temperature change along the length of the combustion chamber at $S=1$, $T_a=573,15K$.

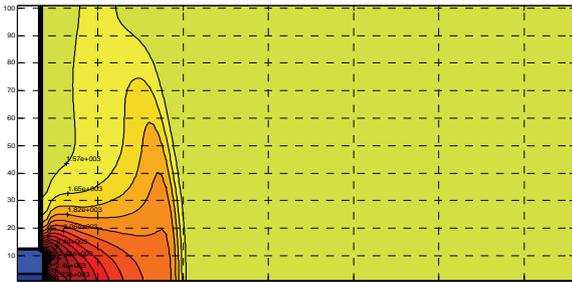


Fig. 7c Contours of the temperature change along the length of the combustion chamber at $S=2$, $T_a=573,15K$.

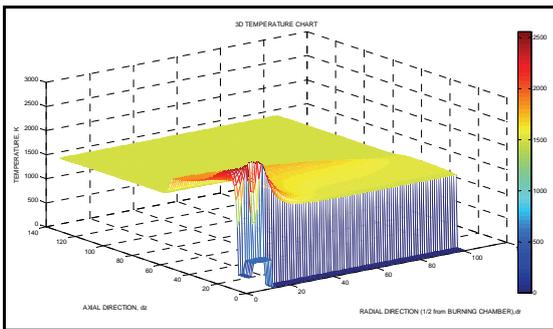


Fig. 8 3D view of the temperature distribution in the chamber.

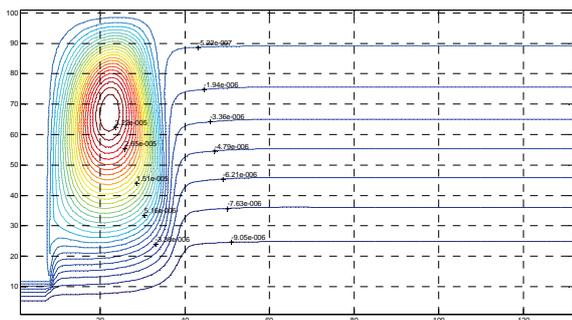


Fig. 9a Contours of the function ψ at $S=0$ and $T_a=300K$.

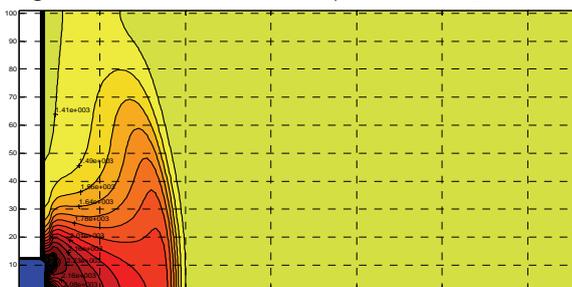


Fig. 9b Contours of the temperature change along the length of the combustion chamber at $S=0$ and $T_a=300K$.

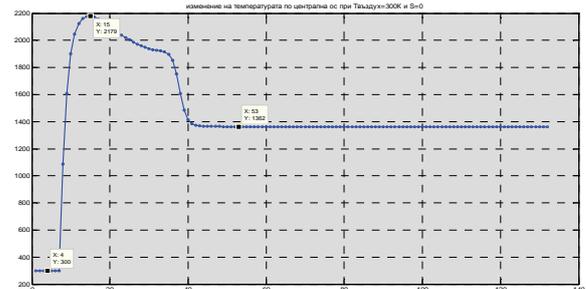


Fig. 9c A temperature change in the central axis of the combustion chamber at $S=0$ and $T_a=300K$.

IV. CONCLUSION

1. With the help of numerical simulation temperature fields in the combustion zone are obtained.
2. By increasing the degree of rotation the length of the torch is reduced. There is also a change of the position of the high-temperature core.
3. The degree of rotation except the intensification of the combustion process can successfully be used for its management, according to the requirements of the technological process.
4. By changing the air temperature, fed into the combustion chamber, additionally on the geometrical and thermal characteristics of the torch are affected.

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