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THERMODYNAMIC OF BURNED GASES IN CONTINUOUS FURNACES FOR ROLLING MILLS

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1. INTRODUCTION

Actually, the geometry of the heating furnace reduces the speed of the burned gases and reduces the intensity of heat exchange by convection and the uniformity of the temperature. The movement of the gases is subject to the geometry and the temperature of the limiting surfaces (the thermal insulation of the furnace). To establish a control of the dynamic of the gases in the furnace it is necessary to establish the variation of the temperature in the section of the furnace and the criteria to analyse the circulation of the gases. When analysing the dynamic of the gases in a heating furnace, the mains criteria took into consideration are: the general aspect of the circulation depending on the configuration and the dimensions of the heating space of the furnace, the distribution of the speeds and pressures inside the furnace, the speed and the pressure of a geometrically determined point of the furnace.

2. INFLUENCE OF THE TEMPERATURE ON THE CIRCULATION OF THE GASES

If the volume of a continuous furnace is compared with a horizontal finite space, the aspect of the recirculated gases streams depends on the temperature difference between the surface of the vault and the surface of the hearth [1].

If the temperature of the vault and of the hearth are the same ($\theta_b=\theta_v$), it means that the circulation in vertical section does not exist. If $\theta_b \neq \theta_v$, ascendant and descendent streams of gases are generated. These streams influence the heat exchange and explain the recirculation.

If the gases have a laminar movement inside the furnace (figure 1) the general equation, which characterises the gases, from energetic point of view, is:

$$\frac{d^2\theta}{dy^2} = 0 \tag{1}$$

Introducing the limit conditions: $\theta\ (h/2) = \theta_b$ and $\theta\ (-h/2) = \theta_v$ it results:

$$\theta = \Delta\theta \cdot \frac{y}{h} + \theta_m \tag{2}$$

where: $(\theta_b - \theta_v) = \Delta\theta$ and $\frac{\theta_b + \theta_v}{2} = \theta_m$

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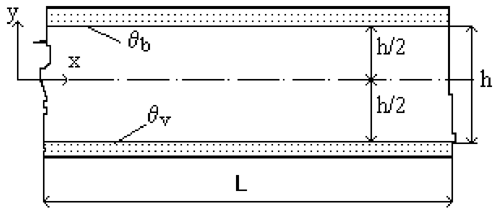

Figure 1. *Elements necessary to establish the influence of the temperature on the recirculation of the burned gases*

Using equation (2) the variation of the temperature in the vertical section of the furnace can be established.

For the laminar flow and for a constant regime of the flue gases the dynamic equation can be written as:

$$\eta \cdot \frac{d^2 w_x}{dy^2} = \frac{dp}{dx} + \rho \cdot g \qquad (3)$$

η- dynamic viscosity of the gases, $m^{-1} \cdot kg \cdot s^{-1}$

w_x- speed of the gases considered on "x" axis of the furnace, $m \cdot s^{-1}$

p- hydrostatic pressure, $m^{-1} \cdot kg \cdot s^{-2}$

g- gravitational acceleration, $m \cdot s^{-2}$

ρ- density, $kg \cdot m^3$

If only the hydrostatic pressure inside the furnace is taken in consideration, the pressure gradient is:

$$\frac{dp}{dx} = -\rho_0 \cdot g \qquad (4)$$

The equation (3) will be:

$$\eta \frac{d^2 w_x}{dy_2} = -\rho \cdot \beta \cdot g(\theta - \theta_m) \qquad (5)$$

Using the equation (2) and introducing the limit conditions:

$$w_x(h/2) = 0 \quad \text{and} \quad w_x(-h/2) = 0$$

It results for the gaze's speed:

$$w_x = -\frac{\rho \cdot \beta \cdot g \cdot \Delta\theta \cdot h^2}{24\eta}\left[\frac{y}{h} - 4\left(\frac{y}{h}\right)^3\right] \quad \text{[m/s]} \qquad (6)$$

In the case of burned gases in the heating furnaces a "*global coefficient of the gaseous phase*", C_g, can be introduced:

$$\frac{\beta \cdot g}{24\nu} = \frac{\rho \cdot \beta \cdot g}{24\eta} = C_g \quad [^oC^{-1} \cdot s^{-1} \cdot m^{-1}] \qquad (7)$$

Finally, it is obtained:

$$w_x = C_g \cdot \Delta\theta \cdot h \cdot y\left[4\frac{y^2}{h^2} - 1\right] \qquad \text{[m/s]} \tag{8}$$

The size and sense of w_x will give information about the gas recirculation in the continuous heating furnaces. In the equation (8) w_x=0 if Δθ=0 or if y=±½·h.

The results given by the equation (2) and (8) were analysed using the computer. As an example are shown the curves in figures 2 and figure 3 for Δθ>0.

The aspects of the speed curve explain the generation of the ascending and descending streams in the section of the furnace. These streams, in interaction with the longitudinal streams, explain the zone recirculation in the continuous furnaces. The value of Δθ determines the sense of the speeds resulted from the dynamic of the gases in the furnace.

3. DYNAMIC OF BURNED GASES IN CONTINUOUS HEATING FURNACES FOR ROLLING MILLS

To analyse the dynamic of the gases in the continuous furnaces a physical hydraulic model was achieved. Therefore it was used the theory of similitude [2, 3].

To analyse the dynamic of the gases in a continuous heating furnace, we have considered the following main criteria [4, 5]: the general aspect of the circulation depending on the configuration and the dimensions of the furnace; the distribution of the speeds and pressures inside the furnace, depending on the speed of the jet of flue gases at the entrance in the furnace; the speed and the pressure of a geometrically determined point, inside the furnace

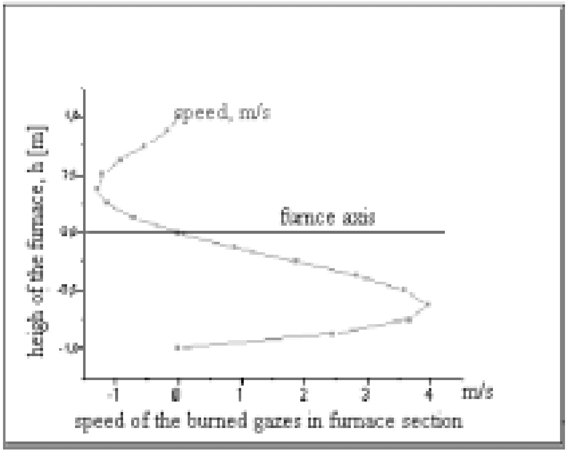

Figure 2. *Variation of the gases speed in the section of a continuous furnace (h=2m, case Δθ>0)*

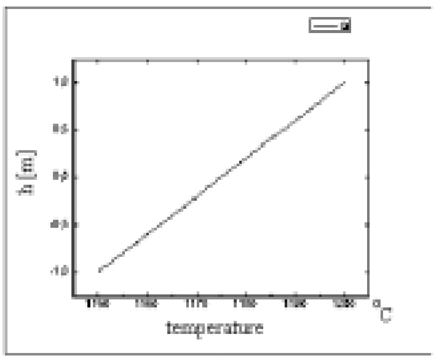

Figure 3. *Variation of the temperature in accordance with the situation in figure 3*

The most important aspects, regarding the dynamic of burned gases, in the case of a walking beam furnace with two heating zones are presented in figure 4.

Starting from the relation established by J.O. Hinze and applying the results of experimental researches [6] (verified for working furnaces) it was established the equation (9) in order to calculate the recycled mass flow of gases:

$$m_r = m_0 \cdot \left(0{,}5\frac{d_{ech}}{r_0} - 1\right) \tag{9}$$

m_r- recycled mass flow of burned gases, $kg \cdot s^{-1}$

m_0- masse flow of burned gases at the exit from the spout of the burner, $kg \cdot s^{-1}$

r_0- burners spouts radius, m
d_{ech}- equivalent diameter of the section of the furnace, m

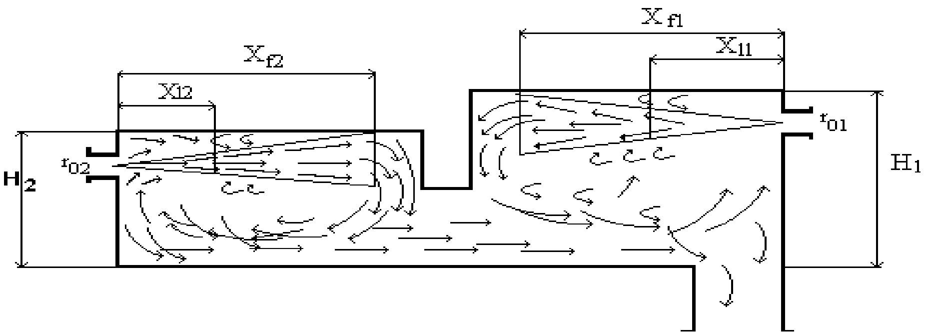

Figure 4: *Flow pattern of the burned gases in the walking beam furnace with two heating zones*

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

Using a physical model to analyse the circulation of the gases in a walking beam furnace (figure 5), it was established that the space in which the jet is developed has the following zones: a mixing zone, where the jet is characterised by an important speed gradient, and a zone beyond the main jet of gases, where the speed is practically constant.

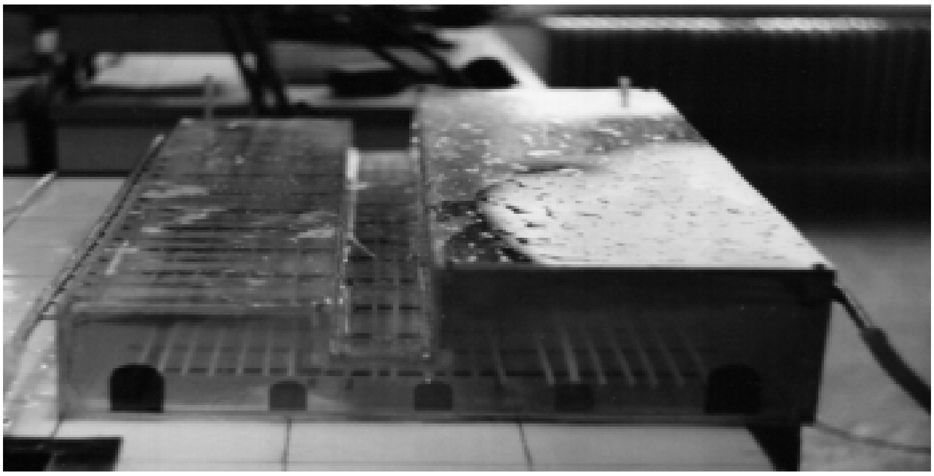

Figure 5. *View of the model used to analyse the dynamic of the gases in a walking beam furnace*

The *recirculation coefficient* of the gases is defined by the ratio

$$K = \frac{V_r + V_{ga}}{V_{ga}} \tag{10}$$

V_r - flow of the gases recirculation, $m^3 \cdot s^{-1}$

V_{ga}- initial flow of the jet of gases, $m^3 \cdot s^{-1}$

The secondary recirculation appears when the gas particles hits the sides that limit the working space of the furnace; part of the quantity of motion of the jet is transformed in pressure, thus creating a pressure difference on the jet main direction. This pressure difference (Δp) generates a quantity of gases that moves above the heated metallic material. The value of pressure difference can be calculated by

$$\Delta p = \frac{w_0^2 - w_1^2}{2} \rho_{ga} \tag{11}$$

w_0- speed of the gases inside the main jet, $m \cdot s^{-1}$
w_1- speed of the gases around the main jet, $m \cdot s^{-1}$

The recirculation degree of the gases in the walking beam furnace, expressed by the coefficient *K*, is determined by the moment when the front of the recirculating gas joints the initial jet. The recirculation coefficient increases when the quantity of motion ($m \cdot w$) grows.

To transfer the experimental results to real situations it was necessary to take in consideration the dynamic aspects and the thermal aspects. It was established the method to transfer the results from the "cold" hydraulic model to the "warm" real furnace. For example, the true flow capacity for the real furnace can be obtained, using the experimental data, by the equation:

$$V_{gar} = D_t \cdot (\mathrm{T} - 1) \cdot \Gamma \cdot \frac{\nu'}{\nu} \tag{12}$$

D_t- experimental flow of the fluid, $m^3 \cdot s^{-1}$
Τ- thermal data transfer coefficient from the model to real working furnace
Γ- dynamic data transfer coefficient from the model to the furnace (it depends on the ratio between the geometrical dimensions of the model and the real furnace)

5. CONCLUSIONS

Analysing both the thermal and the dynamic aspects regarding the thermodynamics of the gases in a continuous heating furnace, it results that the general aspect of the circulation and recirculation in the heating space can be determinate. For example, in figure 6 it is presented the case when the temperature at the vault level is higher than the temperature at the hearth level, that is the situation that frequently appears in a walking beam furnace.

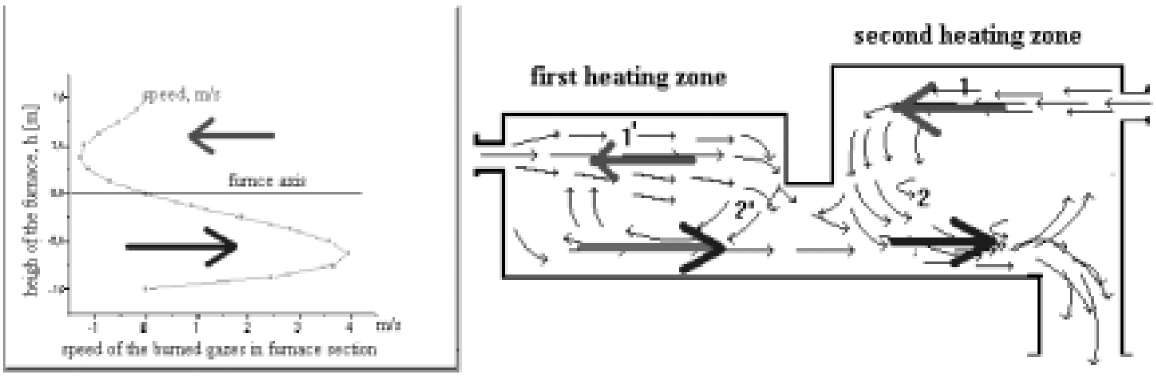

Figure 6. *Influence of the temperature variation in the vertical section of the furnace on the general dynamic of the burned gases (case Δθ>0)*

Analysing the theoretical and the experimental results, we can reach the following conclusions:

- to achieve an optimum influence of the thermal gradient (established on the vertical section of the continuous furnace) on the circulation of the gases, it is necessary to analyse its sense taking in consideration the particularities of each zone of the furnace;

- the thermal gradient influences decisively the recirculation of second degree, around the main jet of gases;

- the situation $\theta_b<\theta$ or $\theta_b>\theta_v$ must be established for each heating zone, in correlation with the thermal regime, necessary to assure a high quality of the heating of the metal;

- these conditions can be achieved by the thermal regime, by the position of the burners and by remodelling of the heating space of the furnace.

In figure 7 is presented a preliminary scheme that is one of the bases of the remodelling of a continuous heating furnace for rolling mills.

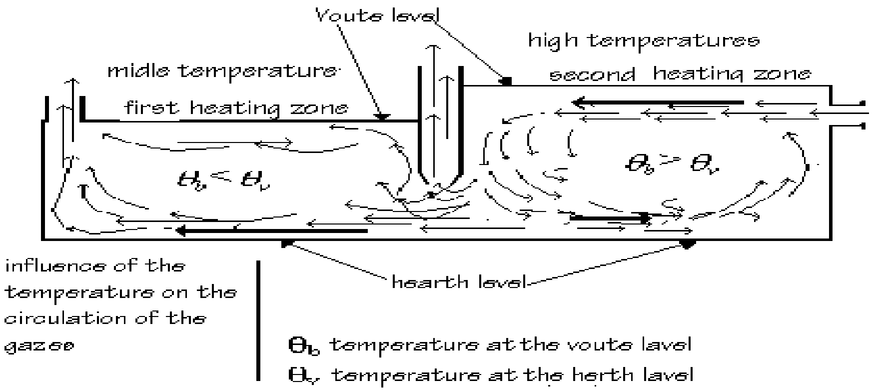

Figure 7: *Influences of the temperature in the vertical section of the furnace and the influence of the evacuation system of the burned gases on the dynamic in the heating space - a preliminary aspect to remodeling the furnace*

6. REFERENCES

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