The Research of the Heat-technological Processes of Phosphatic Raw Materials Agglomeration

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Abstract— **In article results of the analysis of influence of major heat-technological factors on agglomerative process of phosphatic raw materials, in particular the mode of ignition of coke are given in a horn of a sintering machine at a constant temperature of gases on an entrance to a layer. By results of calculations of ignition of an agglomerative layer formation of the combustion front of coke and time is estimated when combustion becomes steady, that is, ignition process is ended. Are analysed influence of heat-technological parameters: an incipient state of distribution of the front of reaction of a decarbonization, a coke burnup, consumption of oxygen on combustion on behavior of system. The dependence of time of ignition of an agglomerative layer on a consumption of gases and temperature of combustion gases is presented.**

Keywords— agglomeration; coke; carbonate dissociation; phosphorite; simulating; combustion

One of the raw material thermal pretreatment ways in metals and phosphoric industry is agglomeration of ore fines by the agency of baking on the belt-type conveyor machine – sintermachine. The processing of nonhomogeneous raw material in phosphoric industry demands initial heat treatment as long as it must meet technological requirements, should be uniformly graded, should not have hygroscopic and chemically bounded water and must contain minimum amount of carbonates and gaseous and injurious impurities. In agglomeration of phosphoric bath different physical-chemical transformations run in the layer concurrently [1]. It happens on the different layer elevation:

- water evaporation;

- ignition of coke particles;

- decorbonation of phosphate rocks and other chemical reactions;

- ignition of coke and batch melting;

- appearing of the sinter;

- sweating in the lower layers.

All of these processes are mostly dependent on heat transfer conditions in the layer [3]. Agglomeration in a layer is one of the most perfect thermally accomplished processes. At fuel consumption from 3 to 7% the charge is brought to a temperature reaching the softening and partial melting for about 1500 ° C in the agglomerate formation zone.

The heat use high efficiency is achieved during the combustion of fuel within the agglomerated layer with a large specific surface of the charge particles, providing a high heat transfer rate between the gas-coolant and the charge [4]. During the agglomeration process the air is supplied to the layer for coke ignition and heat transfer from the heated upper layer to the lower ones. Moreover, the exchange of thermal energy has regenerative nature, that means that the heat carrier, sucked through the layer, transfers heat from the upper layers to the lower [5]. Agglomerate formation zone is moved down at a rate which is determined by conditions of heat transfer and the flow rate of the physical-chemical transformations.

While analyzing the initial stage of the heat exchange in the layer, the drying rate, gas temperature and the material in this stage must be assessed. Considering that during the drying the raw part of the material has a wet-bulb temperature that varies only slightly, the temperature of the material can be considered as constant one.

We are to analyze the basic rations to describe the drying of agglomeration charge when applying the layer with gas with temperature t_{g_0}. Consider the evaporation surface. Let us assume that gas and particles at the surface are in equilibrium at a wet bulb temperature t_m. Particles are spherical, uniformly wetted and uniformly streamlined with gases in constant evaporation speed mode [2].

The heat balance of the gas is represented by the equation:

$$-\rho_g c_g W_g \frac{dt_g}{dy} = \alpha_V \left(t_g - t_m \right) \qquad (1)$$

Border conditions $y=0$, $t_g = t_{g_0}$.

where: c_g – gas heat capacity, α_V – volumetric heat transfer coefficient, t_g – the gas temperature in the layer, y – adjustment layer coordinate, W_g – gas velocity in the layer.

The solution of equation (1) with the specified boundary conditions has the form:

$$t_g = \left(t_{g_0} - t_m\right)\exp\left(-by\right) \qquad (2)$$

where : $b = \alpha_V \big/ \left(c_g W_g\right)$.

The change in moisture content of the material in the layer is also related to the heat balance and is described by the equation:

$$\rho_m L_e \frac{du}{d\tau} = -\alpha_V\left(t_g - t_m\right) \qquad (3)$$

Initial conditions: $\tau=0$, $u=u_i$.

where u – the moisture content in the charge, u_i – initial moisture content of the charge, L_e – heat moisture evaporation, τ – time.

Integrating equation (3) with appropriate initial conditions and with using (2) gives the relation:

$$u = u_i - \frac{\alpha_V}{\rho_m L_e}\left(t_{g_0} - t_m\right)\exp\left(-by\right)\tau \qquad (4)$$

The balance of the vaporized moisture provides an opportunity to assess the moisture content in gases x_w, with an initial moisture content of gases x_{w_i}:

$$-\rho_m \frac{du}{d\tau} = \rho_g W_g \frac{dx_w}{dy} \qquad (5)$$

where ρ_m – material density, ρ_g – gas density.

From where by integration with initial conditions $y = 0$, $x_w = x_{w_i}$ and taking into account (2 - 4) we obtain the following equality:

$$x_w = x_{w_i} - \frac{\alpha_V b}{\rho_g W_g L_e}\left(t_{g_0} - t_m\right)\left[1 - \exp\left(-by\right)\right] \qquad (6)$$

Upon reaching the top layer of the charge equilibrium moisture content with the gases u_e after the time τ_e the downward movement of dried zone begins, i.e. the vaporization front starts to move. The time interval τ_e is calculated from (4) provided that: $y = 0$, $\tau = \tau_e$, $u = u_e$,

$$\tau_e = \left(\left(u_i - u_e\right)\left(t_{g_0} - t_m\right)\right)\big/\left(\alpha_V\big/\left(\rho_m L_e\right)\right) \qquad (7)$$

To analyze the front of the evaporation let us assume that until the charge warming up in the evaporation front immediately, the gases are cooled to a temperature of t_{g_ξ}. From the heat balance at the evaporation front, we obtain an equality for the speed of the evaporation front:

$$\frac{d\xi}{d\tau} = \frac{\alpha_V}{\rho_m L_e}\left(t_{g_\xi} - t_m\right)\bigg/\left(\frac{du}{dy}\right)_{y=\xi} \qquad (8)$$

Thus, for estimating the drying rate it is necessary to know the temperature of the gas at the evaporation front t_{g_ξ} and the value $\left(\dfrac{du}{dy}\right)_{y=\xi}$.

The proposed mathematical model of heat transfer during sintering process allows to analyze the influence of the main factors on the agglomeration process in the first approximation. Let us demonstrate the research of the model on the example of describing the coke ignition mode in the hearth sintering machine.

The ignition process involves the heating of the charge to a temperature when the heat is sufficient to sustain combustion due to chemical reactions [6]. Agglomeration process can be divided into two stages: 1) the ignition, taking place in the hearth sintering machine; 2) sintering of the charge during the supply the oxidant to the layer and the coke particles combustion.

The further course of the agglomeration process greatly depends on the quality of the first step. The excessive heating of the charge in the ignition stage can lead to poor gas permeability of the layer and the reducing of sinter cake strength. The temperature unevenness of the hearth volume is the cause of poor quality ignition.

The process in the hearth sintering machine goes with an oxidant supply, the amount of which depends on the coefficient of excess air that supplied to the burner and the suction cups. The oxygen concentration at the bed inlet estimated from the relation:

$$C_{O_2} = 0,21\frac{\left(\alpha - 1\right)V_a^0 + V_b}{V_h + V_b} \qquad (9)$$

where V_a^0 – theoretically required combustion air volume; V_b, V_h – air volume due to the suction cups and the products of combustion in the hearth sintering machine respectively.

After the hearth the oxygen concentration is changing, since the air is supplied to the layer. The temperature of gases supplied to the layer in the hearth without losses to the environment, can be calculated from the heat balance for the hearth:

$$T_{g_0} = \frac{Q_f^c + Q_{as} + Q_{fs}}{c_g V_g} \qquad (10)$$

here Q_f^c – calorific value of fuel gas; Q_{as}, Q_{fs} – the sensible heat of air and fuel.

The check of the adequacy of the mathematical model of heat transfer showed the satisfactory quantitative and qualitative description of the processes. Ignition process analysis was conducted at a constant temperature of gases entering the layer. The coefficient of heat transfer from the gas to the particles was estimated by the Timofeev's formulas. Data on the thermal properties of phosphate rock were taken independently of temperature.
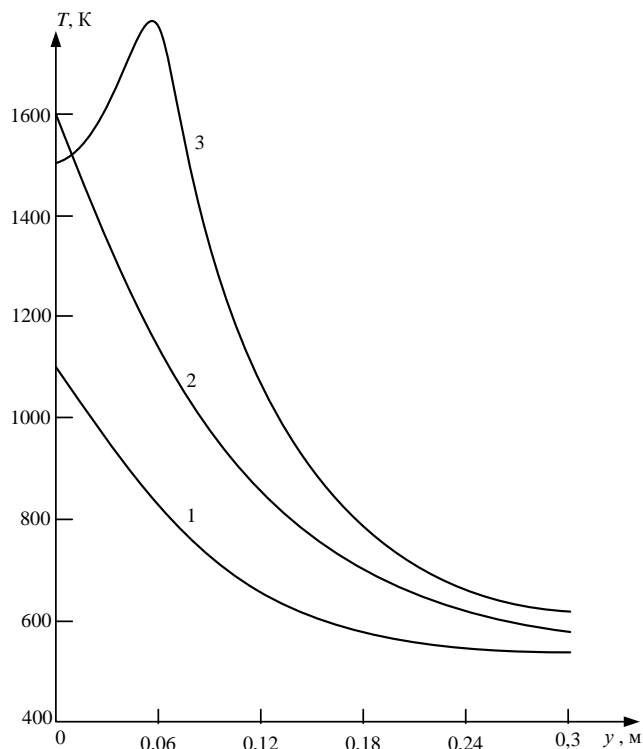

Fig. 1. The temperature distribution of the charge in the ignition mode. 1- τ =90s, 2 - τ = 120s, 3 - τ = 170s

According to the calculations results of ignition, Figure 1, the formation of coke ignition occurs in the front depth of 0,06m. In this case, the ignition becomes stable, that means the ignition process is ended. Thus, when the ignition requires heating of the upper layer of the charge with a finite thickness that coincides with practical results.
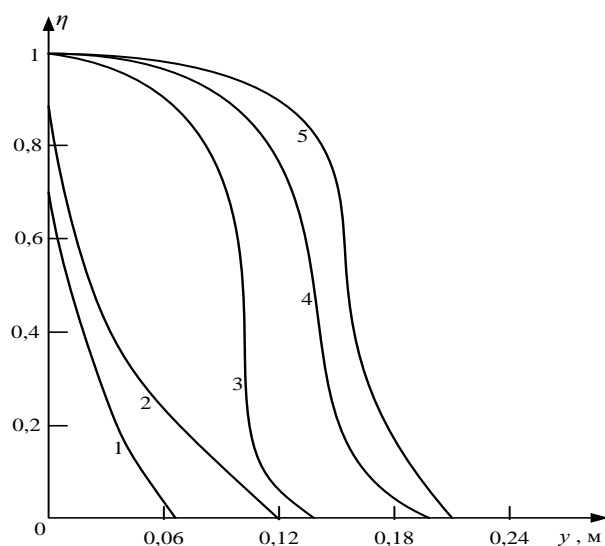

Fig. 2. Distribution carbonate concentration in ignition mode of the agglomeration layer. 1 - τ = 90s, 2 - τ = 120s, 3 - τ = 150s, 4 - τ = 170s, 5 - τ = 190s
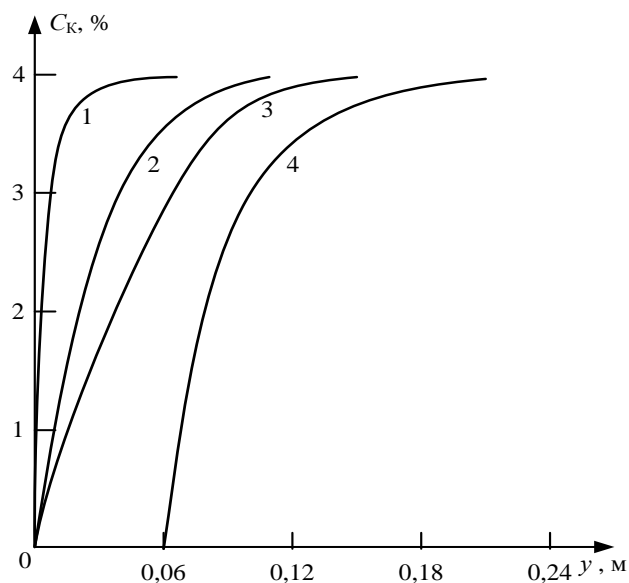

Fig. 3. Distribution of coke concentration in ignition mode of the agglomeration layer . 1 - τ = 90s, 2 - τ = 120s, 3 - τ = 150s, 4 - τ = 170s
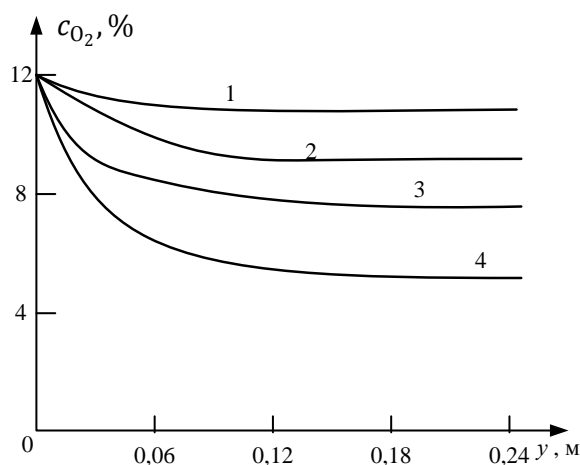
Fig. 4. The distribution of the oxygen concentration in ignition mode of the agglomeration layer . 1 - τ = 90s, 2 - τ = 120s, 3 - τ = 150s, 4 - τ = 170s

The process of removing the moisture and carbonates dissociation occurs almost simultaneously with the coke ignition and captures the relatively narrow area by the layer height. The initial stage of the decarbonization front clearly seen in Figure 2. In this case, at the initial stage the ignition of the coke is carried out, Figure 3, and the oxygen consumption for combustion, figure 4. Model gives quality depending on the thermal process parameters and allows us to analyze the effect of any parameter on the behavior of the system.
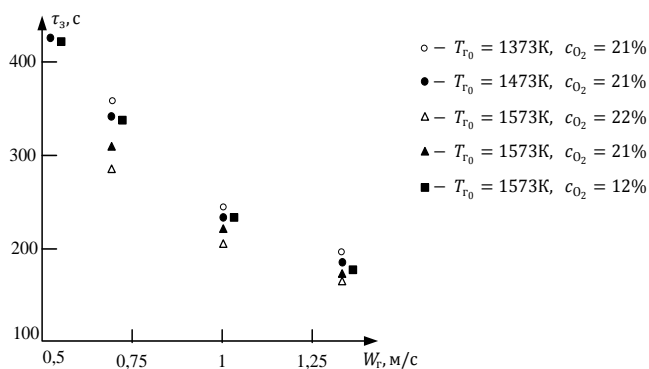

Fig. 5. The ignition time in the various modes of gas flow into the layer of the charge.

In particular, the dependence of the ignition timing from the gas flow (normal gas feed velocity in the layer) and temperature of combustion products is shown in Figure 5. It is obvious, that the intensity of thermal processes in the layer not only affects the gas temperature, but also affects the speed of sucking gas, increasing which, the energy exchange between the gases and the charge also increases [7]. This suggests that increasing the feed rate of the gas at the initial stage of ignition, can achieve a more reliable ignition and, due to the intensification of warming-up the charge, to reduce heat losses in the hearth of the sintering machine.

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