Conference Paper

Study of Heat Exchange Processes During Roasting of Iron-ore Pellets

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Abstract

The method for approximate calculation of heat exchange in a layer of iron-ore pellets is developed, based on the regularities of heat transfer in the stationary layer. It is noted that the duration of oxidizing roasting of iron-ore pellets on a belt of the conveyor-type machine is influenced by the conditions of heat exchange, distribution of temperatures of gas and material along the height of the layer; the physical and chemical processes occurring in the layer of pellets during its heating (magnetite oxidation, decomposition of carbonates, etc.) have a great influence. Most of them flow with the release or absorption of heat. As a result, the calculation of heat exchange in the roasting layer of pellets is a complex problem. It is shown that it is not possible to obtain a solution of the system of equations describing the heat exchange in a layer of pellets in the general case, but only approximately using stepwise approximation of the boundary conditions and parameters of the problem, or by a numerical method with the help of a computer, which is considered in this article. With the help of the drawn-up program, the calculation of heat exchange in the layer of pellets has been carried out with respect to the mode of their roasting on a conveyor-type machine. The considered method has a great practical application, since it allows determining the optimal duration of the pellet roasting process, taking into account the effect on heat exchange of various factors, and consequently, the specified degree of completeness of all physicochemical transformations in the treated layer to obtain a high-quality product.

Keywords: heat exchange, calculation method, iron-ore pellets, physical and chemical processes, layer, conveyor-type machine, roasting, temperature, solution, approximation, parameters, problem, numerical methods, duration, boundary conditions

1. Introduction

The calculation of oxidating heating of iron-ore pellets is based on the regularities of heat transfer in the stationary layer, which is a special case of heat exchange in the cross flow. The time for heating of the layer and, consequently, the productivity of a conveyor-type roast machine depends on many factors: thermophysical properties [1–5] and pellet sizes; physical and chemical processes occurring in the layer when the pellets are heated; flow rate and temperature of the heat-exchange medium. Therefore, the search for the optimal roasting of pellets is a complex problem. The solution of the problem in general form is even more complicated, since the change in the heat exchange conditions results in a change in the baking conditions, that is, quality of roast pellets. Therefore, the role of preliminary calculations of thermal regimes of roasting of a layer of pellets increases.

The calculations of heating of the layer are complicated by dependence of the thermophysical properties of pellets and heat-exchange medium on temperature, the presence of internal heat sources in the layer, associated with the occurrence of chemical reactions. At the same time, analytical solutions as for heat exchange in a layer have some or other limitations that narrow the range of their application [6, 7].

2. Method of the Approximate Calculation of Heat Exchange in a Layer of Pellets

When using analytical methods, it is expedient to calculate by calculation the position of the isotherm along the height of the layer, that is, determine the temperature dependence of the height of the layer and time. This allows us to take into account the variability of the thermophysical properties of pellets selected by the specified temperature of the isotherm. In order to determine the temperature field in the layer, it is expedient to calculate by means of 5–7 isotherms. In addition to analytical methods for calculation of the layer heating, numerical methods using computers are also being used.

In practice, approximate methods for calculation of the heat exchange in the layer are used, taking into account the linear-step approximation of the boundary conditions, when the curve of distribution of the initial temperature of the layer $t_M(h,0) = F_M(h)$ is approximated stepwise, and the curve of the gas distribution over time $t_S(0,\tau) = F_S(\tau)$ is approximated linearly. The last method has found wide application. At present, it is more promising to use universal software programs suitable for different conditions for such calculations. This method of calculation is discussed below.

The equations describing heat exchange in the stationary layer are written in the form:

$$\left.\begin{aligned}\frac{\partial t_S}{\partial h} &= -\frac{k_V}{c_S w_S}(t_S - t_M);\\ \frac{\partial t_M}{\partial \tau} &= \frac{k_V}{\rho_H c_M}(t_S - t_M),\end{aligned}\right\} \tag{1}$$

where t_r – gas temperature, °C; t_M – material temperature, °C; k_υ – volumetric heat transfer coefficient, W/(m^3°C); h – layer height, m; c_r – gas specific heat, J/(m^3°C); w_r – speed of gas filtration, m/s; τ – time, s; ρ – pour density of material, kg/m^3; c_M – heat capacity of material, J/(kg°C).

Heat transfer coefficient k_υ is determined from the equation:

$$k_V = \frac{6C\lambda_S(1-m)}{d^2[Re^{-n} + 0,1C\lambda_S/\lambda_M]}, \tag{2}$$

where $d = 2R$– pellet diameter, m; C and n – coefficients from the following equation $Nu = CRe^n$(Nu and Re – Nusselt and Reynolds numbers), λ_r – coefficient of gas heat conduction, W/(m°C); λ_M – coefficient of pellet heat conduction, W/(m^{o}C).

If we assume that the characteristics of pellets and gas do not depend on temperature, then the system (1) is solved analytically. In the actual conditions of the heat exchange process in the layer, the thermal and physical characteristics of the gas and the material, like the value of k_υ, depend essentially on the temperature. Therefore, the system (1) turns out to be nonlinear:

$$\left.\begin{aligned}\frac{\partial t_S}{\partial h} &= -K_1(t_S, t_M)(t_S - t_M);\\ \frac{\partial t_M}{\partial \tau} &= K_2(t_S, t_M)(t_S - t_M),\end{aligned}\right\} \tag{3}$$

where $K_1 = k_V/(c_S w_S)$, $K_2 = k_V/(\rho_H c_M)$.

The system (3) could not be analytically solved except for the cases when the dependences $K_1(t_r, t_M)$ and $K_2(t_r, t_M)$ are rather simple. Therefore, a practical method for solving system (3) is a numerical method, in particular, the method of grids.

We divide the layer in height by several layers, height Δh, and we will consider the temperature change during the time intervals Δτ. Connecting the points $h = \sum \Delta h_i$ and $\tau = \Delta\tau_K$, we obtained a grid (Figure 1(a)). Basically, it could be calculated in two

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ways: by the grid nodes, by the inter-nodes of the grid. The volume and accuracy of the calculations depend on the adopted method.

Figure 1(b) shows a separate grid cell. Writing the system (3) in the finite differences (Figure 1(b)) and taking to reduce the number of indices $t_S = \vartheta_S$, $t_M = t$, we obtain a system of equations for finding the temperature $t_{i,k}$ and $\vartheta_{i,k}$:

$$\left.\begin{aligned} t_{i,k} &= \frac{(b_1+q)\Delta Z + b_2(2+\Delta Y)}{2+\Delta Z+\Delta Y}; \\ \vartheta_{i,k} &= \frac{(b_2-q)\Delta Y + b_1(2+\Delta Z)}{2+\Delta Z+\Delta Y}, \end{aligned}\right\} \tag{4}$$

where $q = \vartheta_{i-1,k-1} + \vartheta_{i-1,k} + \vartheta_{i,k-1} - t_{i-1,k-1} - t_{i,k-1} - t_{i-1,k}$; $b_1 = \vartheta_{i-1,k-1} + \vartheta_{i-1,k} - \vartheta_{i,k-1}$; $b_2 = t_{i-1,k-1} + t_{i,k-1} - t_{i-1,k}$;

$$\Delta Y = k_1(\bar{\vartheta}_{i,k}, \bar{t}_{i,k})\Delta h; \Delta Z = k_2(\bar{\vartheta}_{i,k}, \bar{t}_{i,k})\Delta \tau.$$

Formulas (4) allow finding temperatures at the fourth point i, k along the three points of the grid cell.

Figure 1 shows the grid cell for the method of calculation by the internodes of the grid. In accordance with the cell scheme, we write the system of equations (3) in the finite differences. We will have the following:

$$\left.\begin{aligned} t_{i-\frac{1}{2},k} &= \frac{2\Delta Z\vartheta_{i-1,k-\frac{1}{2}} + t_{i-\frac{1}{2},k-1}(2-\Delta Z-\Delta Y)}{2+\Delta Z+\Delta Y}, \\ \vartheta_{i,k-\frac{1}{2}} &= \frac{2\Delta Y t_{i-\frac{1}{2},k-1} + \vartheta_{i-1,k-\frac{1}{2}}(2-\Delta Y+\Delta Z)}{2+\Delta Z+\Delta Y}. \end{aligned}\right\} \tag{5}$$

The calculations using formulas (4) will be more precise. However, formulas (5) are more easily programmed, especially from the point of view of taking into account the initial and boundary conditions. Below, when calculating heat exchange in a layer on a computer, formulas (5) are used as more simple for programming.

The program is developed for calculation of the heat exchange in the pellet layer as applied to the roasting regime on the conveyor-type machine. The calculation covers the pellet-heating zone, divided into two subzones, the roasting zone and the recovery zone.

We will consider the specific examples of calculation of heat exchange in a layer of pellets. The program provides for the possibility of varying many parameters of the

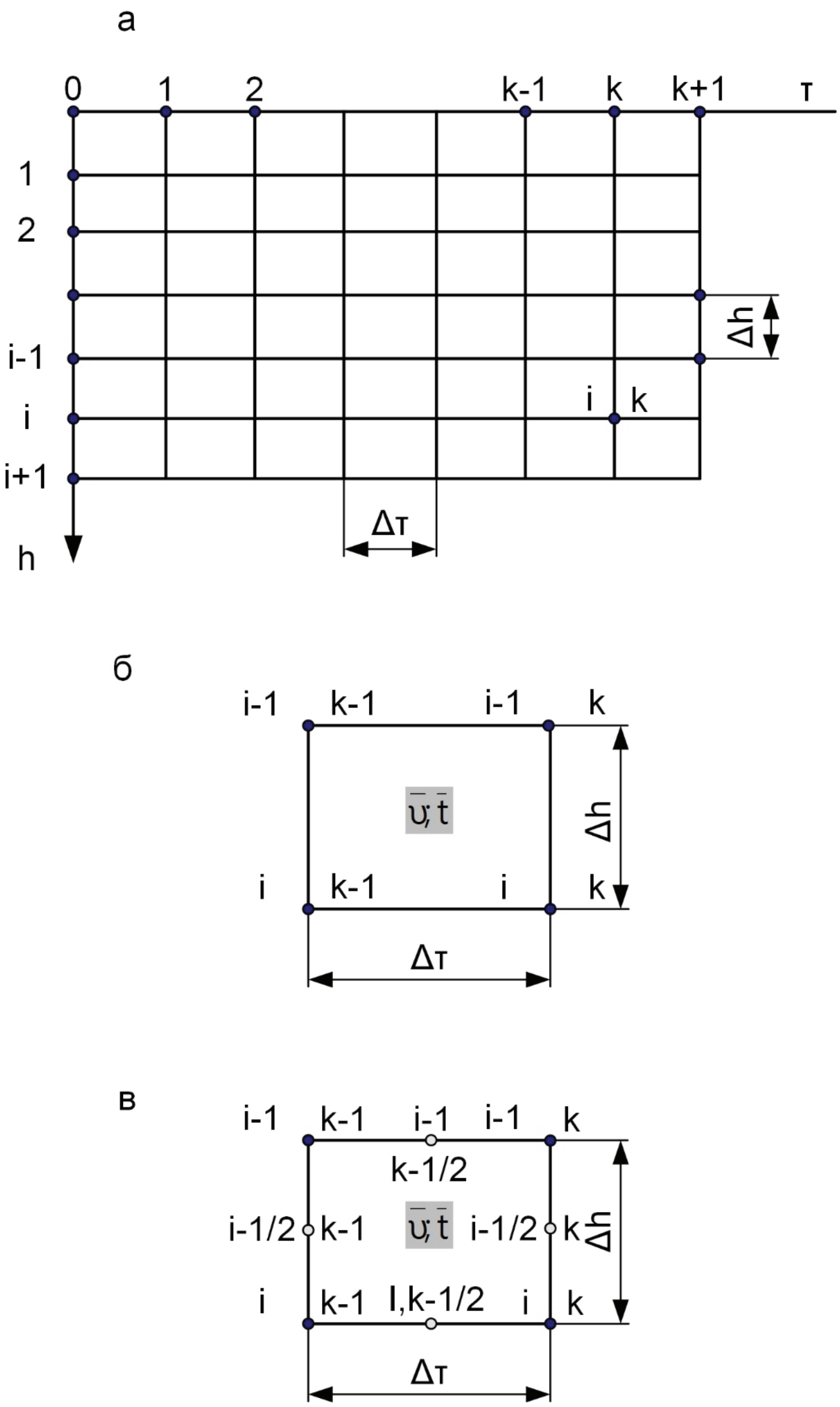

Figure 1: Explanations to the calculation using the grid method.

problem, in particular, c_M, $c_г$, $w_г$, λ_M, $\lambda_г$, etc., in a wide temperature range from 0 to 1400°C. The initial temperature of the pellets is tabulated, the temperature of the gas at the layer inlet is set by the linear functions in each calculation zone (I is heating zone, II, III is roasting zone, IV is recovery zone).

The heat transfer coefficient α_F was determined from known formulas [8]:

$$\left.\begin{aligned} Nu &= 0,106Re, \quad \text{Re<200}; \\ Nu &= 0,61Re^{0,67}, \quad \text{Re>200}, \end{aligned}\right\} \tag{6}$$

and according to the author's formula [9], obtained as a result of experiments on the sinter pot and having the form:

$$Nu = 0,000282Re^{1,5}. \tag{7}$$

The results of the calculation are shown in Figure 2. The experimental data are also given there. It can be seen that the calculation according to formula (6) significantly underestimates the heating time, and by formula (7) – no less significantly overestimates. Obviously, in relation to our experimental conditions, the value of α_F should occupy some intermediate value in comparison with the extreme variants used in calculation.

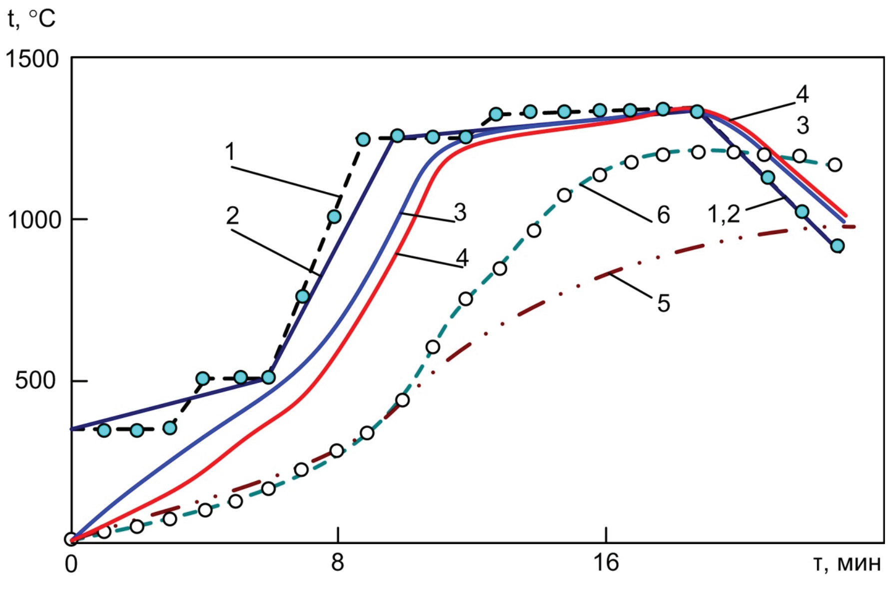

Figure 2: Change in temperature of gas and pellets during roasting in the sinter pot: 2–5 – by calculation; 3, 4 – by the formula (6); 5 – by the formula (7); 6 – from the experiment; 1, 2 – gas temperature at the layer inlet; 3–6 – temperature of pellets; distance from the surface of the layer 100 (3.5), 200 (4) and 120 mm (6).

In the calculation, the following parameters, determining solutions of the problem, have been taken. The initial temperature of dry pellets is the same everywhere and is equal to 20°C. The speed of the belt moving is assumed to be 1 m/min, and the length of zones I-IV is calculated so that the time for passage of the zones by the pellets corresponds to the experiment on the sinter pot. The thermophysical characteristics of pellets are taken in accordance with the literature data [1]. The thermophysical characteristics of the heat carrier gas are taken from the data of work [10]. The time of calculation of the layer with a height 0.5 m is 6 – 8 min.

3. Summary

The method for the approximate calculation of heat exchange in a layer of pellets is developed, which is based on the solution of the problem under unspecified boundary conditions. The problem is simplified by using the linear-step approximation method, which has a higher accuracy than other methods. The program is developed for calculation of the heat exchange in a layer of iron-ore pellets as applied to their roasting on a conveyor-type machine, allowing considering the change in many parameters of the process. It is implemented on a concrete example of the practical calculation of heat exchange in a layer of roast pellets.

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