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Optimization of Thermal Processes in Industrial Conditions

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Abstract

On basis of the developed models of dependences of thermal processes, industrial conditions are received, having extreme character.

Keywords

Mathematical Model, Optimization, Dynamic Characteristic, Static Characteristic, Process of Burning, System Control of Extreme

1. Introduction

Presently, constitutive and operational data of the thermal technological units are described by the broad dispersion used in metallurgy and other industries impeding the comparative analysis of their operation. As a result, in the process of calculating the units the characteristics of the burning of a torch are set on the approximate empirical equations. This decreases the accuracy of the calculation and leads to the losses of thermal energy in industrial units causing an essential decrease in technical and economic indicators at the time of continuously increasing fuel prices.

The share of the burned-out fuel on torch length significantly depends on coefficient of surplus of blasting (a consumption of air on fuel unit). This is the share of the burned-out fuel reaches a maximum in some point on the torch length which designates a kernel of a torch [1]. The deviation of coefficient of surplus of blasting from optimum value at a size of ±0.1 leads to reduction of a thermal stream from a torch on a surface of heating to 10% that leads to significant increase in fuel consumption.

To optimize the processes for a torch kernel in the course of fuel burning, the researchers formulated the equation of thermal balance:

$$G_f \cdot q_f \cdot dt + G_v \cdot c_v \cdot T_v \cdot dt + G_f \cdot c_f \cdot T_f \cdot dt = G \cdot c \cdot T_t \cdot dt \tag{1}$$

where G_f: fuel consumption, kg/sec; q_f: calorific ability of fuel, kJ/kg; G_a: air consumption, kg/sec; c_v: thermal capacity of air, kJ/(kg·°C); T_a: air temperature, °C; c_f: a thermal capacity of fuel, kJ/(kg·°C); T_f: fuel temperature, °C; $G = G_f + G_v$: consumption of products of burning, kg/s; c: a thermal capacity of products of burning, kJ/(kg·°C); T_t: torch temperature, °C; P: mass of burning fuel, kg.

In the established mode, $dT_t / dt = 0$.

Having made a number of substitutions, the temperature of products of burning of a torch will become:

$$T_t = \frac{G_f \cdot q_f + G_v \cdot c_v \cdot T_v}{\left(G_f + G_v\right)c} \qquad (2)$$

As a solution to the problem, the researchers developed the mathematical model of the burning of a torch of the gaseous fuel as a valid process in the broad spectrum of the change of parameters, which will lead to the justified thermal calculations of the industrial units [2].

The research investigated the fuel of the following structure: $CH_4 = 60\%$, $C_2H_6 = 4\%$, $C_3H_8 = 10\%$, $C_4H_{10} = 0.5$ of %, $C_5H_{12} = 0.05$ of %, % $H_2O = 10.45$, $N_2 = 15\%$. For this fuel, calculated values of parameters as as follows: thermal capacity of products of combustion $c = 1.4707$ (kJ/kg·°C), calorific ability of fuel $q_f = 34927.81$ (kJ/kg), amount of air necessary for full oxidation of 1 (kg) of fuel equals 12.49 (kg). Therefore, the consumption of air in a kernel of a torch will be $G_{vt} = 12.49$ (kg/sec) with the fuel consumption of 1 (kg/sec).

The program for calculating the temperature of a torch depending on a consumption of air has the following form:

$$T_t\left(G_v\right) = \left|\begin{array}{ll} T_t \leftarrow \dfrac{G_v \cdot q_f / G1_{vf} + G_v \cdot c_v \cdot T_v}{\left(1 + G_f\right) \cdot c} & if \quad G_v \leq G_{vf} \\[3mm] T_t \leftarrow \dfrac{G_f \cdot q_f / G_{vf} + G_v \cdot c_v \cdot T_v}{\left(1 + G_f\right) \cdot c} & otherwise \\[3mm] T_t \end{array}\right. \qquad (3)$$

The researchers conducted a calculating experiment using Mathcad software and identified the dependence of the torch temperature on the air consumption with varying gas consumption (**Figure 1**).

The sensitometric curve has an extreme character and the temperature maximum is reached with the complete full fuel combustion at optimal air consumption in a torch kernel. The optimum is displaced with the change in fuel consumption, change in fuel composition, or change in burning conditions.

The ultimate research task involved the search of the air consumption optimum, which will provide complete burning of the fuel corresponding to the extreme value of the temperature.

Figure 2 shows schedules of dependence of temperature of a torch from composition of natural gas with change of air consumption. The researchers obtained these schedules using Equation (3).

Fuel composition and conditions of its combustion in industrial conditions change continuously. Necessary air consumption that provides fuel savings when burning in an optimum mode must be adjusted to these changing
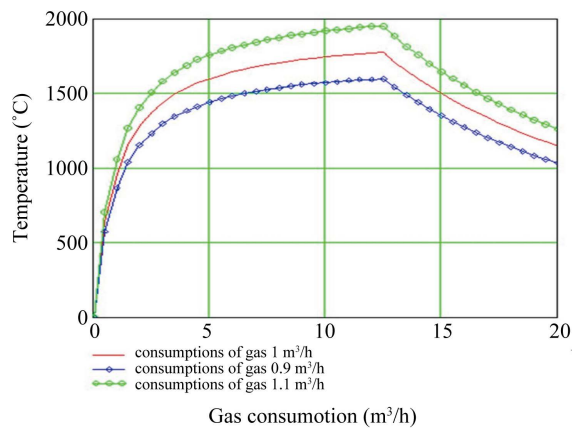
Figure 1. Charts of the dependence of the torch temperature from the gas consumption in a torch kernel.
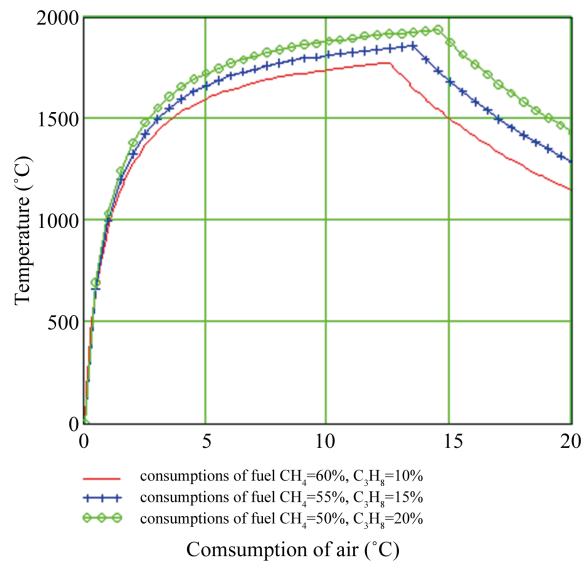
Figure 2. Shift of temperature maxima depending on air consumption.

conditions. For this purpose, it is necessary to use the system of optimum control of burning process that has to conduct continuous search of the maximum of temperature in a torch kernel changing air consumption [3].

Researchers received similar results for the process of the kiln roasting of the zinc concentrates in the "fluidized bed" and production of zinc in general. The process of roasting is characterized by the complex dynamics and belongs to the inertial objects of control. Therefore, the purpose of control of the process consists in the provision of an optimal static mode of operation. To solve the stated problem, the researchers developed the mathematical model of process of kiln roasting of zinc concentrates, basing their mathematical on the ratios of material and thermal balance [4].

The equation of thermal balance for the zone of boiling layer in the established mode is defined by the ratio:

$$G_c \cdot q_c + G_v \cdot c_v \cdot T_v + G_c \cdot c_c \cdot T_c = G \cdot c \cdot T_b \tag{4}$$

where G_c: concentrate consumption (kg/sec); q_c: calorific ability of the concentrate, (kJ/kg); G_v: air consumption (kg/sec); c_v: a thermal capacity of air (kJ/kg·˚C); T_v: air temperature, ˚C; c_c: thermal capacity of the concentrate (kJ/kg·˚C); T_c: temperature of the concentrate, ˚C; $G = G_c + G_v$: consumption of products of roasting, (kg/sec); c: thermal capacity of products of roasting (kJ/kg·˚C), T_b: temperature in the boiling layer, C.

Ratio (4) shows that the amount of heat arriving with the concentrate and air as a result of roasting is counterbalanced by waste heat and temperature increase in the boiling layer. From here temperature in a boiling layer can be determined as follows:
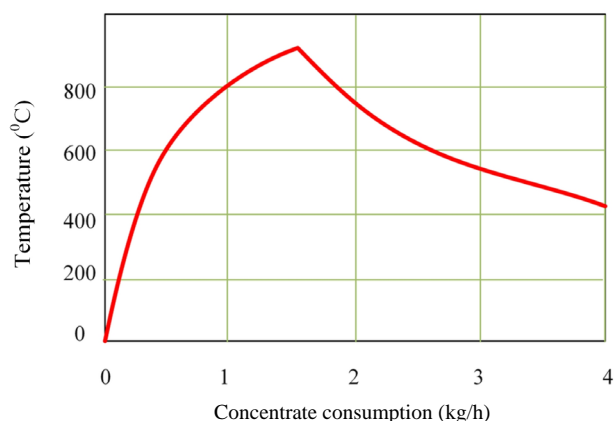
$$T_b = \frac{G_c \cdot q_c + G_v \cdot c_v \cdot T_v + G_c \cdot c_c \cdot T_c}{(G_c + G_v)c} \tag{5}$$

Let us make some assumptions that essentially will not affect the type of the static characteristic of burning. We will neglect the member $G_c\, c_c\, T_c$, as this amount of heat with constant concentrate consumption is disparagingly small in comparison with the member Gc qc. Besides, we believe that the thermal capacity of products of burning is independent of the temperature, that is $c = const$ in the entire interval of temperatures.

Let us review an example. According to the practical experience of one of the factories, there is a furnace charge of the following structure: *Zn*: 50%, *Pb*: 1.5%, *S*: 32%, *Cu*: 1%.

Full oxidation of 1.852 kg of the concentrate requires $G_{vc} = 5.54$ kg of air. Therefore, the amount of air needed for full oxidation of 1 kg of a concentrate will make kg. Composed $G_c\, q_c$ will depend on the air consumption until this consumption equals 5.54 kg/sec. The proportion that defines this dependence is $\dfrac{1}{2.991} = \dfrac{G_c}{G_v}$.

To calculate the temperature of the boiling layer, the Equation (5) is formulated through the Mathcad-program:

Figure 3. Dependence of the temperature of the boiling layer on the concentrate consumption.

$$T_c(G_v) = \begin{vmatrix} T_c \leftarrow \dfrac{G_v \cdot q_c / 2.991 + G_v \cdot c_v \cdot T_v}{(G_c + G_v) \cdot c} & if & G_v \leq G_{vc} \\[4mm] T_c \leftarrow \dfrac{G_c \cdot q_c + G_v \cdot c_v \cdot T_v}{(G_c + G_v) \cdot c} & otherwise \end{vmatrix} \tag{6}$$

Researchers conducted the calculating experiment using the Mathcad software and identified the dependence of the boiling layer temperature on the concentrate consumption (**Figure 3**).

The sensitometric curve displays the extreme character of the dependence. The influence of the perturbation action on the dependence leads to the shift of the extremum and the rise of drift of the static characteristic.

Output parameter of the roasting process, temperature in the "fluidized bed" furnace, is defined by the amount of the burned cinder and by the amount and temperature of the incoming air. The cinder does not burn completely with the small amount of air, and this, therefore, reduces productivity of the process. With excess of air in the "fluidized bed" furnace, fuel of the furnace charge burns completely, but much of the heat released during its combustion is used to heat the excess air and is carried away from the furnace with products of burning and excess air.

At a certain ratio of the amount of cinder and incoming air, the temperature mode of the "fluidized bed" furnace will be optimal corresponding to an extremum of the output parameter of the process.

At the optimum consumption of the concentrate, its full oxidation is provided, and the temperature reaches its maximum. Consequently, the purpose of managing the roasting process is reduced to maintaining optimum performance of the "fluidized bed" furnace operation, where in a continuous mode its maximum productivity is reached with the change of conditions of conducting the process and limited aprioristic information about it.

The process of roasting of zinc concentrates belongs to inertial control objects and is characterized by difficult dynamics. Change of the key regime parameters of the process may lead to a drift of the position of the optimum of studied dependence. Consequently, provision and long-term maintenance of the optimum static mode of the studied process may be realized based on the use of the extreme control systems. Stabilization of the process is reduced to the repeated solution of the interconnected problems of defining the extreme position of the working point and the organization of movement toward it.

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