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Analysis of Energy Efficiency of Furnaces for High Temperature Treatment of Carbon Materials

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Abstract

The paper analyses efficiency of high temperature treatment of carbon materials in electrofurnaces with dense and fluidized beds. Departing from specific power consumption for furnaces of different types, the main guidelines for improving their thermal operation have been outlined. Hydrodynamic working modes ensuring consistent heating of material, have been determined for furnaces with electrothermal fluidized bed.

***Key words**: carbon material, high temperature treatment, calcinator, electrothermal fluidized bed*

The quality of metallurgical products depends directly on the characteristics of charging and consumable materials, including carbon, that are used. For example, it is typical for the aluminum production processes, where anodes are consumed of 450-500 kg per 1 t of product in electrolyzers, as well as for the electric furnace steelmaking, where graphite electrodes are consumed of 4.5-10 kg per 1 t of electrical steel [1]. Thus, the improvement of the consumable carbon materials quality directly affects the development of metallurgical technologies, that explains the considerable interest among metallurgists to aggregates and carbon materials preparation processes [2, 3].

The main development trends of carbon materials production are the quality improvement, primarily due to the higher purity of materials, and the development and implementation of energy efficient methods of heat treatment [4].

The raw material for the production of graphitized carbon products are coke, anthracite and natural graphite. The principle of technological process consists in the feedstock heating to a temperature of 2000-2700 °C followed by the soak, in course of which there is a partial raw material greying, removal of sulfur, volatile products, metals and their oxides, which are a part of the ash.

The Temperature of Calcination, ° C.

Known furnace units for the high temperature treatment of carbon materials with the external heating use (gas and electricity) [4] provide the heat treatment of raw material to a temperature not exceeding 900-1400 °C. In this case the spcific electrical resistance of the treated material is reduced from the 10000 to 1000 mkOm·m level [4]. It allows to use the high temperature resistive electrical warming in bed at the final step of heat treatment. At present, two main technological processes of high temperature treatment of carbon material are known: during the heating of dense and fluidized bed.

The heating process in a dense bed is realized in electric pit-type calcinator (Fig. 1), where the preheating of raw material up to 900 °C and the subsequent resistive heating up to 2000 °C are performed in one aggregate by passing the current between the upper and lower electrodes directly through the coal dense bed with the particles size of 6-25 mm. A leading Ukrainian electrodes manufacturing enterprise PLC "Ukrgrafit" uses this technology option.

The continuous process is implemented in elektric pit-type calcinator during the sequential movement of material bed through the heating, baking and cooling zones. The process of high temperature resistive heating is determined by the heat sources capacity and distribution, that is, by the current distribution along the radius and height of the material bed located between the electrodes. The studies carried out under industrial conditions, showed that the heat sources distribution in the volume of elektric pit-type calcinator is uneven during the electric heating process [5]. It causes the central portion overheating of the anthracite, located near the electrodes, which in turn leads to the increase of current nonuniformity along the radius as the specific electrical resistance of the anthracite bed decreases with the temperature increase. [4] As a result, the quality of the end product (thermoanthracite) moving at the periphery of the electric calcinator lining-up does not meet set requirements due to a low treatment temperature. As a result, it is necessary to use the material reprocessing in calcinator (two-step mode) to increase the power consumption significantly to a level of 1360-1380 kWh/t of end products. The problem can be solved in two ways: a rational order of electrodes [3] and a change in the proper form [4]. Thus, reducing the distance between the electrodes up to 1500 mm allows to perform one-step calcination process with a specific energy consumption of 1300-1330 kWh/t [3]. A change in the proper form with a breaker core (dashpot) installation in the calcination zone provides a coal "mixing" during its vertical movement and provides a current uniform distribution in the narrowed section of the electric calcinator shaft. All this allowed to improve the heating quality, go to the one-step calcination mode and reduce the energy consumption to 500-600 kWh/t of end products. A similar result was obtained on the equipment of ELKEM company [4] during the transition to an oval section of calcinator shaft and the horizontal positioning of electrodes. In this case the specific energy consumption is not more than 500 kWh/t.

Thus, the use of electric pit-type calcinators provides the given electrical resistance thermoanthracite production during specific energy consumption of 1380-500 kWh/t. In this case a partial combustion of raw material is used for the energy supply of the process due to air leaks in the furnace proper [4]. It should be noted that carbon materials cleaning is not always acceptable during the heating to the 1250-1400 °C temperatures. There is a rise of purity requirements for the carburizing material in production of so-called new generation metals. Thus, the processing temperature of carbon materials, designated by the world's leading manufacturers, reaches the level of 2000 °C and higher. The increase of the electric pit-type calcinators treatment temperature requires their radical reconstruction. At least, the materials used for their lining-up and consisting of mullite-corundum refractories with a softening temperature of 1580-1600 °C must be replaced.

An alternative to the high temperature treatment in the dense bed is the use of furnaces with electrothermal fluidized bed.[5-7]. The use of neutral gaseous atmosphere, which excludes extensive chemical reaction of gases with the graphite blocks linning-up furnace is required to implement the process of the carbon material high-temperature heating (2500-2700 °C). Given this, the industrial company American Energy Technologies Co. (AETS) proposed a two-step calcination of the graphitized carbon precursor technology, which comprises the first step - the feedstock heating to a temperature of 900-1200 °C to remove most of the volatile impurities, and the second step - the high-temperature processing of partially purified raw material in furnaces with electrothermal fluidized bed at a temperature up to 2800 °C.

The first treatment step can be performed in gas heating furnaces (rotary, cyclone) or indirect electric heating furnaces (muffle rotating, furnaces with the pulsating or dish hearth bottom), as well as in a resistance heating furnace with the end product heat treatment system [4]. The specific energy consumption comparison for the first processing step of carbon material is presented in Table 1.

Energy consumption for gas heating furnaces increases primarily due to additional energy losses at the expense of the heat carried away by the combustion products departing from the furnace proper.

Table 1 Specific energy consumption during calcination of pet coke

Furnace type	Gas heating furnaces (rotary, cyclone)	Indirect electric heating furnaces (muffle rotating, furnaces with the pulsating or dish hearth bottom)	Resistance heating furnace
Specific energy consumption, kWh/t	925 -850	890-400	200-100

The furnace, which schematic diagram is shown in Fig. 2. is used for the second step of heating. The furnace operates continuously, the material enters the fluidized bed of the carbon material 6 having particle sizes of 0.2-2 mm. The bed is heated by the current passing from a central electrode 2 to a peripheral electrode 3. The heated material is fed through the central hole of an air distributor plate 5 to a water-cooling refrigerator 7 and further taken out from the furnace at a temperature not higher than 300 °C.

The availability of fluidized bed solves several technologic and technical issues simultaneously: allows to increase the electrical resistance of a bed compared with the electrical resistance of a dense bed of the carbon material particles; provides the removal of volatiles and fumes from the furnace working chamber during the high temperature heating; provides conditions for the material uniform treatment due to its intensive stirring. The analysis of data on the magnitude of the fluidized bed electrical resistance [5, 6] showed that the magnitude of electrical resistance increases 4-7 times during the transition from the dense to boiling bed and further increases with the bed void fraction growing. Electrical resistance decreases with the temperature and amperage increase. These data can be explained on the basis of the conduction mechanism in a fluidized bed [5]. This mechanism involves the formation of the contact chains between particles, their destruction and re-formation, which leads to the significant heat output in the particles contact areas. It is obvious that the particle concentration decreases with the increase of bed volume and velocity of the gas, entering the bed. Accordingly, the amount of contact chains decreases, and the bed resistance increases. At the same time, the gas ionization and the increase of bed conductivity are possible due to the conduction increase of the gas gap between particlesduring the temperature increase up to 2000 °C or more.

The feature of the carbon material heating in the furnace considered construction (Fig. 3) is connected with a change in cross-section area of the conductive bed when changing the radius. The minimum area corresponds to the radius of the central electrode $r_1 r_1$. The maximum one - to the inner radius of the peripheral electrode $r_2 r_2$. The area increase results in a change of the electrical resistance, wich magnitude for the elementary bed $dr\ dr$ is of the form

$$dR = \rho \frac{dr}{S} dR = \rho \frac{dr}{S},$$

where $R\ R$ - electrical resistance, Ohm;

$\rho\ \rho$ - specific electrical resistance of the material fluidized bed, Ohm·m; S = 2πrh – area of the bed, perpendicular to the current flow direction, m^2; h - height of the furnace proper, m.

Taking into account that the total amperage I in any bed cross-section remains constant, the distribution of the heat sources power during the resistance heating is of the form

$$dN = I^2 \frac{\rho}{2\pi h} \frac{dr}{r} dN = I^2 \frac{\rho}{2\pi h} \frac{dr}{r}.$$

Modelling of the fluidized bed heating process, based on solving the issue of the one-dimensional problem of heat conduction for a hollow cylinder with internal heat sources at adiabatic boundary conditions on its surfaces, allowed to estimate the temperature differential along the radius of the heated bed and the temperature distribution at the steady-state furnace conditions. The elementary heat balances method and iterations method were used in the calculations. A change in the specific electric resistance of temperature on the first step was not taken into account and assumed as constant over the cross-section and equal to $\rho = \rho =$ 0.048 Ohm·m. The magnitude of bed effective heat conduction, which is determined on the basis of equality of the diffusion coefficient and the fluidized bed heat conduction coefficient was used to take account of the heat transfer in the fluidized bed [7]. The value varied in calculations from 0.3 to 700 W/(mK). The upper value corresponded to magnitude estimates given in [7]. The significant value of the fluidized bed heat conduction coefficient both in vertical and horizontal directions is predetermined by intensive circulation of the material in form of particle packets, which are typical for the developed fluidization modes with bed void fraction equal to 0.5-0.6. The minimum value of the investigated range of the effective heat conduction coefficient is typical for a dense bed of discrete material, which is determined by the heat conduction of the gas-filled gaps between the particles.

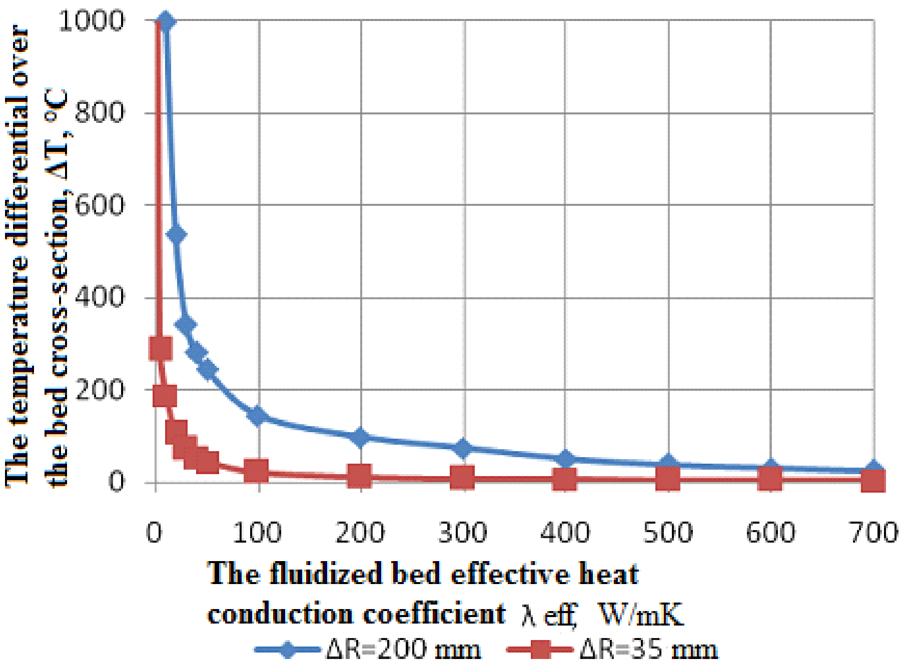

Figure 4 Dependence of the temperature differential over the fluidized bed cross-section on value

The calculation results (Fig. 4) showed that the temperature differential over the fluidized bed cross-section is determined by the effective heat conduction value and the fluidized bed geometric dimensions (distance between electrodes). Since the temperature difference reaches 2000-3000 °C in the absence of circulation in the bed mode (buckling dense layer), what excludes the heat treatment process stabilization. The temperature differential value decreased to ΔT = 50-200 °C during the effective heat conduction increase up to 50-100 W/mK at a distance between electrodes ΔR = 35-200 mm, respectively. Further increase in the bed heat conduction results in a smooth decrease of temperature differential to 4-25 °C.

Thus, the implementation of the high temperature treatment process of carbon materials in electrothermal fluidized bed in conditions of the current radial direction is possible while the fluidization developed mode. To be exact, the material mixing process determines the choice of the fluidizing gas supply parameters.

Calculations of material and thermal balance of electrothermal furnaces with fluidized bed (Table 2) showed that the specific power consumption of the carbon material high temperature treatment in furnace with capacity up to 1 t/h are equal to 1500-1700 kWh/t of an end product. In this case, power consumption is determined by the losses in the heat of the end product, which is removed from the furnace (more than 90% of consumed power). That is, the end product heat utilization is the main way to improve the thermal performance of furnaces with electrothermal fluidized bed.

Table 2 Heat balance of furnace with electrothermal fluidized bed with capacity of 1 t/h

Income items			Expenditure items		
Name	kW	%	Name	kW	%
Raw material heat	12	0.7	End product heat	1563	91
Nitrogen heat	0	0.0	Waste gases heat	3	0.1
Electric power	1706	99.3	Loss heat	78	4.6
			Water cooling	74	4.3
Total amount	1718	100		1718	100

Conclusions

The main directions to improve the performance efficiency of carbon material high temperature treatment furnaces for metallurgy exigencies are temperature increase to 2500-2700 °C and energy consumption decrease.

Existing furnaces with a so-called dense bed provide the raw materials processing up to a temperature of 2000 °C with a specific energy consumption of 1380-500 kWh/t.

The processing temperature increase can be implemented by the two-step technology proposed by AETS: the first-step - raw material processing at a temperature of 900-1200 °C; the second-step - high temperature treatment (2500-2700 °C) in a furnace with electrothermal fluidized bed. Specific electricity consumption for each step is respectively equal to 200-900 and 1500-1700 kWh/t.

A promising way to improve the furnace design of two-step ATEC technology is to use the waste end product heat to preheat raw material. Implementation of this direction at the first processing step allowed to reduce the energy consumption to 200 kWh/t.

Selection of the performance modes of electrothermal furnaces with fluidized bed and coax position of electrodes is determined by the characteristics of the original and heat-treated material, the hydrodynamic mode of fluidized bed in the furnace proper, which affect the choice of the basic geometrical and technological parameters of furnace: fluidizing gas consumption, amperage and voltage across the electrodes.

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