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INCREASING THE UNIFORMITY OF METAL HEATING IN CHAMBER FURNACES BY INFLUENCE OF THE ELECTRIC FIELD*

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Abstract

The article is devoted to the possibility of increasing the energy of efficiency of gas chamber furnaces. For high-quality metal heating in a chamber furnace is proposed to use spatial electric field. It is empirically proved that there are optimal values of electric field control factors for chamber furnaces with a pull-out hearth, which reduce fuel consumption and produce quality of heating of metal, namely: high uniformity of heating.

Keywords: chamber furnace, control algorithm, efficiency, electric field

1. Introduction

The priority is the need to reduce the consumption of primary fuel and energy resources through the introduction of the latest energy efficiency and energy saving measures in various industries. The environmentally friendly technologies are being developed in the way of fossil fuels in Ukraine for coal utilization, for example, in the form of gasification and combustion of coal-water fuel (Pinchuk et al., 2020), etc. This reduces natural gas consumption. However, it isn’t possible to completely replace natural gas fuel. In general, gas consumption in Ukraine may be described as excessive and irrational.

Nowadays, there are many metallurgical factories that widely use obsolete chamber heating and thermal furnaces, which are heated by natural gas. Although, the technical efficiency of most furnaces requires full or partial modernization but economically it isn’t always profitable. The available publications analysis on the problems of improving the

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energy efficiency of chamber furnaces, showed that the aerodynamics of the latter is not rational.

It is known that to influence the direction of heat flow in the furnace can improving of its aerodynamics by changing the position of the burners and exhaust windows (Liush, 2015). The large metal work pieces is placed in the area that accounts for the largest percentage of total heat energy is a technically difficult task, and to concentrate heat in the area of the work piece without a significant change in the direction of heat flow is impossible. Therefore, at this work mathematically formulated problem of constructive optimization of the chamber furnace and on the basis of method of dynamic programming created an algorithm for optimal feed control gas to the furnace during the whole time of heating of metal products. However, the above algorithm is rather cumbersome in terms of practical use due to the complexity of the developed model.

The authors (Kachan et al., 2017a, 2017b, 2017c) proved the possibility of controlling the flow of flue gases by using a spatial electric field in the furnace chamber. That's why it was decided to optimize the algorithm (Kajukov, 2013) by full-factor process control of heating the metal with the additional use of a spatial electric field in the chamber furnaces.

The main purpose of this study is to confirm the possibility of using of the electric field to improve the uniformity of the temperature distribution of the metal in chamber furnace.

To achieve this goal the following tasks were solved:

- modeling of metal heating process at different directions of furnace gas flows in cameras;
- determination of the optimal direction of furnace gas flows;
- conducting a model experiment of the influence of the electric field on aerodynamics of furnace gases.

This will increase the energy and exergy efficiency of gas chamber furnaces by redistribution of furnace gas aerodynamics in the furnace space. Improving energy efficiency is done by reducing gas consumption, and exergy efficiency increases due to more uniform heat transfer processes that improve the quality of metal heating in the furnace chamber.

This article is divided into three main parts:

- problem of statement and determination of boundary conditions for the zonal method;
- assessment of metal heating and gas consumption in the furnace before and after the application of space of electric field that changes the aerodynamics of furnace gases;
- analysis of results, drawing conclusions and formulating recommendations for managers and technologists of enterprises in the metallurgical industry.

2. Materials and methods

2.1. Influence of an electric field

The question of the influence of electric fields (especially weak, with a voltage up to 1000V) on the formation of heat fluxes is not sufficiently studied and remains open. It is known in the chemical transformation that occurs by means of a branched chain process, the reaction can be intensified by introducing active centers into the gas mixture of (radicals, atoms, ions). The latter interact with great activity - often with almost zero activation energy. The speed of these acts is determined by the frequency collisions of these centers with other components of elementary processes. With the total rate of chemical transformation is high even at low concentration of active particles. Therefore, it is possible to adjust the speed of the combustion process by influencing the frequency of collisions of the active centers with an electric field.

Although the stationary homogeneous flame is generally electrically neutral, but in it has opposite charged particles, which are also unevenly distributed. Zone of reaction and the outer cone are characterized mainly by a positive charge, and the inner -negative. This separation of charges of different names is caused by different mobility of positive ones ions and negative particles - electrons. And this indirectly confirms that source the electrification of a flame is a chemical reaction that develops in its front.

The positive ions formed as a result of combustion due to their low mobility remain mainly at the place of its origin, when at the same time obtained more mobile electrons quickly leave the front of flame and form a predominantly negative charge in inner cone. Therefore, the presence in a flame charged particles in a fairly large (compared to equilibrium) concentrations and conditioned the proposal on the possibility of the influence of the electric field on the combustion process due to its local action on those present in a flame charged components.

2.2. Mathematical model

The research of the problems considered in the article is based on the ideas of classical aerodynamics and the theory of heat and mass transfer in furnaces. The zonal method was used for analytical solution of systems of differential equations (Adoniev, 2017).

The task of external heat transfer is performed using the following assumptions:

1) steel billets of rectangular cross-section, stacked on the rolling floor the working chamber of the furnace in one layer without gaps, presented in the form of an infinite plate;

2) the presence of three heating zones in the furnace provides symmetrical heating of the workpieces;

3) thermoelectric thermometer is a two-layer ball (outer layer made of corundum, the inner cavity of the ball is filled with metal working joint sensor);

4) thermoelectric thermometer is a two-layer ball (outer layer made of corundum, the inner cavity of the ball is filled with metal working joint sensor).

The zonal model of external heat transfer was presented by a closed system corresponding to the upper part of the working space of the furnace chamber (Fig. 1). It is formed by the surfaces of metal, masonry, thermoelectric thermometer and filled with flammable gases. To account for changes in the composition of combustion products and the optical properties of the environment in the direction of development of the torch, the selected part of the working space of the furnace chamber was divided into twenty seven zones: five volumetric zones of torch zones and combustion products (I=1…5),five flat surface of metal zones (I=6….10), seventeen flat of surface of masonry zones (I=11….27) and one spherical surface zone of a thermoelectric thermometer (I=28).

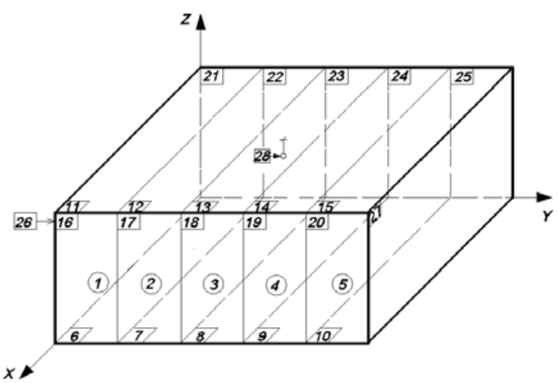

Fig.1. Scheme of the zonal model of external heat exchange in the working chamber of heating furnace.

2.3. Performance criteria
2.4.

To assess the effectiveness of the proposed algorithm for controlling the heating process, we use the coefficient of utilization of fuel heat, which largely determines the value of the specific heat consumption. The most well-known means of increasing fuel efficiency is heat recovery by heating the combustion components with flue gases leaving the furnace. In turn, this leads to a reduction in the length of the torch and the ability to work with less excess air, reduces the cost of heating by reducing heat loss from the exhaust gases.

Because the fuel efficiency of the furnace and the uniformity of the temperature distribution inside its chamber depend on the type of burners used. The use of state-of-the-art recuperative and regenerative burner devices with automatic control and various operating modes (pulse combustion and high-speed torches) allows reducing gas consumption and increase fuel efficiency.

2.5. Optimization methods

To optimize this algorithm, empirical studies were performed on a chamber furnace of a metallurgical enterprise in Zaporozhye, Ukraine.

3. Resutls and discussion

The main problem with the energy efficiency of chamber furnaces is that most of them are morally and physically obsolete and have shortcomings due to the imperfections of their aerodynamics. And this leads to the irrationality of the temperature distribution in the chamber and, as a consequence, energy consumption, which is especially noticeable in the context of a significant increase in gas prices and the impossibility of replacing it with other fuels. Fig. 2 shows the calculated picture of the distribution of temperature zones in the furnace chamber, in which the highest temperature is observed in its upper part and is concentrated in the volume which is forty one percent relatively of general, at the same time the metal cage is in an area with a much lower temperature (Cheilytko and Yerofieieva, 2019).

In the practice of heating metal in chamber furnaces, before processing the metal by pressure, use multi-period heating modes. Thus, the heating mode is determined by: steel grade, shape, size and location of the metal in the furnace, its design and purpose.
The proposed electric field significantly improves the performance of the temperature regime for periodic furnaces and reduces the efficiency of the chamber furnace fuel utilization rate. It is proposed to use the voltage between the torch and the cage and the amount of gas consumed as control effects.

The modeling of factors influencing the energy efficiency of the chamber furnace was also performed using the composite method of geometric modeling (Belokon et al., 2016). The method is based on the point calculation of Balyuba-Naidysha. He involves the geometric formalization of all input factors (parameters) and the construction of geometric matrices. This makes it possible, during modeling, to operate simultaneously values of different physical nature. The method also allows convenient 3D-visualization of all stages of modeling and application of the obtained model in the information system of control of metal heating modes.

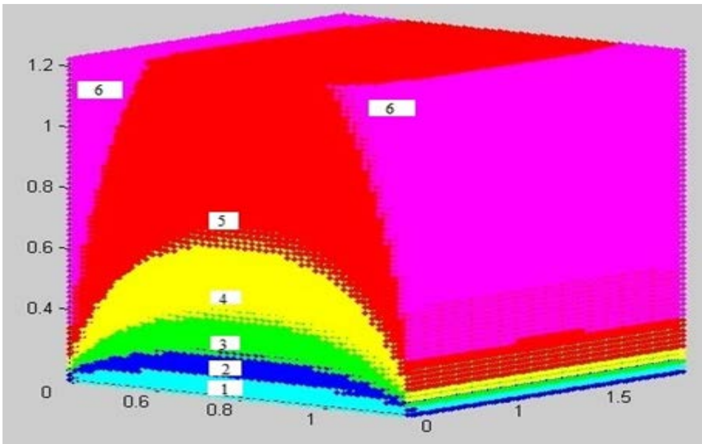

Fig.2. Distribution of temperature zones in the chamber furnace (1215 minutes from the beginning of the heating process): 1)755 – 820 °C; 2) 820 – 885°C;3) 885 – 950°C; 4) 950 – 1015°C; 5) 1015 – 1080°C; 6) 1080 − 1145°C.

To clarify the parameters of the model, empirical studies were conducted on a chamber furnace of a metallurgical enterprise in Zaporozhye, Ukraine. The task was to reduce the coefficient use of fuel by a chamber furnace and improve the quality of metal heating by economically feasible methods. The use of secondary energy resources at the enterprise has already been involved. The composition of natural gas used at the enterprise is given in Table. 1. Humidity of gas is 10 g/m^3. Steel grade, the quality of heating of which had to be improved: steel grade - U12 (C = 1.1 ÷ 1.3%; Mn = 0.5 ÷ 0.8; Si = 0.25 ÷ 0.5%; P and S not more than 0.045 ÷ 0.04%; Cr and Ni - 0.3 %).Overall length of the furnace is 5.22 m. Width of the furnace is 4.06 m. Pulse heating was used to increase the efficiency of the chamber furnace. ZIO KPOMSCHRODER 165 HB 300/35 regenerative burners are installed in the system.

The heating of the metal in the furnace consisted of two periods and three intervals. Temperature at the position of 100 °C. The first period consists of three intervals with a heating rate of 60 °/h: heating from 100 °C to 500 °C; heating from 500 °C to 1000 °C; heating from 1000 °C to 1300 °C. The temperature at the position of 100 °C. The second period - exposure at a temperature of 1300 °C. The heating temperature of the metal is shown in Fig. 3.

An electrically conductive plate was installed on the roll-out area with an area of about 5 m 2, which did not exceed the size of the lower plane of the metal cage and withstood the temperature in the heating chamber.

Table 1 Natural gas warehouse used at a metallurgical enterprise in Zaporozhye, Ukraine.

C_2H_6	C_3H_8	C_4H_{10}	CO_2	O_2	CH_4	C_5H_{12}	N_2
1.79	0.5	0.09	0.27	0.006	96.08	0.02	1.22

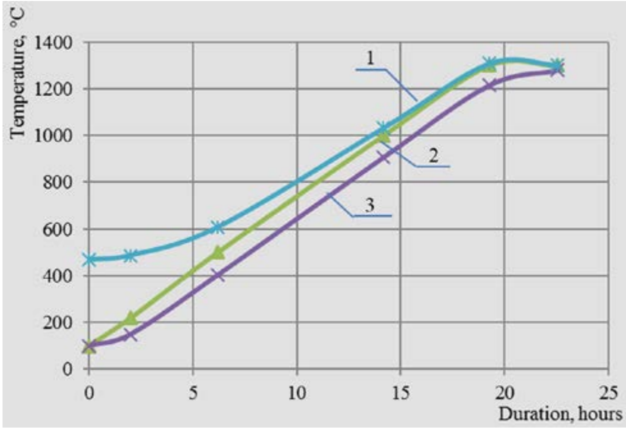

Fig.3. Temperature of heating the metal in the chamber furnace: 1 - temperature of the metal center, 2 - masonry temperature, 3 - metal surface temperature.

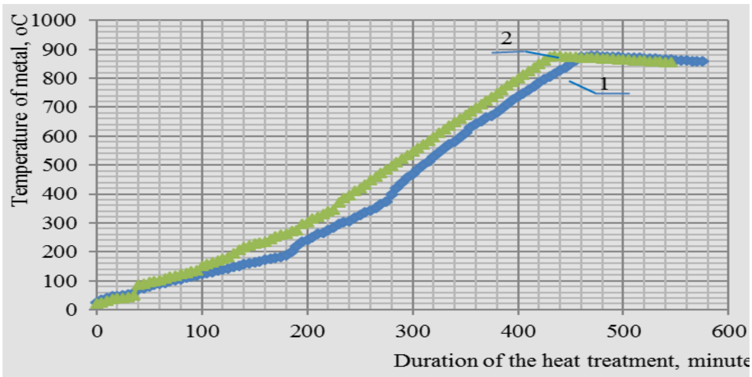

Fig.4. Graphs of experimental values of annealing temperatures of metal: 1 - without voltage supply, 2 - under voltage of 1000 V on a metal cage

An insulated current conductor was connected to the plate, which was brought out so that there was no contact with the hearth housing (there was no grounding). A metal cage weighing about 4500 kg was placed on the pull-out floor so that electrical contact was maintained between it and the plate and it was possible through the existing hole in chamber of the furnace with a non-contact device to determine the temperature of the cage during heating. Another insulated current conductor with the same cross section was fixed on the injection burner so as to ensure its electrical contact with the latter. The opposite ends of these conductors were connected to a rectifier with a voltage (not more than 1000 V) so that the burner had zero potential. Natural gas consumption was measured by a gas meter type RG 40, the values of the temperature of the cage and the vault - contactless laser pyrometers Optris LaserSight (Kachan and Yerofieieva, 2018), the structure of the metal was studied using metallography (Belokon et al., 2016). The experiments were carried out in compliance with the temperature-time regime of annealing set by the technology metal, the results of which are shown in Fig. 4.

Fig. 5 shows the dynamics of natural gas consumption in the basic mode and under the condition of using an electric field in the process of heating and holding the metal cage. Jumping on the graphs correspond to the alternate switching on of the burners.

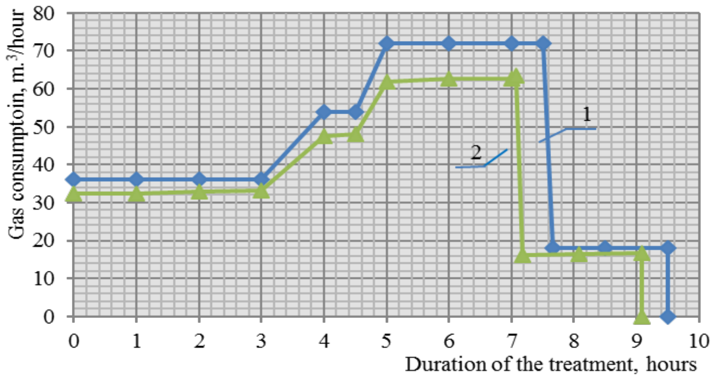

Fig. 5. Dynamics of gas consumption for the chamber furnace: 1 - without voltage supply, 2 - under voltage of 1000 V on a metal cage.

The analysis of the obtained data showed that the required metal temperature is reached and a more rectilinear annealing curve is observed. This unequivocally proves greater uniformity and ensuring improved quality of metal heating in the chamber furnace. A change in the fuel utilization factor in the metal heating mode without voltage supply and in the heating mode with voltage supply between the burner and the metal cage has been recorded. In general, the use of voltage has reduced the consumption of natural gas in the chamber oven on 11 percent (Belokon et al., 2016).

4. Conclusions

For high-quality heating of metal in the chamber furnace, it is proposed to use a spatial electric field, which will increase its energy efficiency. For one cycle of heat treatment it is possible to reduce natural gas consumption by up to 11%. The simplicity of the technical implementation of the method indicates that it can be used in any enterprise where similar furnaces are used.

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