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Study of Thermal Performance of Modern Design of the Drum-type Batch Furnace

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Abstract

The report focuses on the layout and features of the thermal performance of the drum-type batch furnace for heating of metal products for hardening. Technical characteristics of the furnace, some results of the thermomechanical calculation are given. The computer simulation of the processes of gas flow and heat exchange in the furnace is presented. The study has been carried out using the CAE-system (CAE, Computer Aided Engineering)—the software module ANSYS Fluent. In this module, the flow boundary conditions were specified. To check the repeatability of calculations, the control of current values and calculated temperature discrepancies has been used. The results of the simulation are presented graphically and contain a visualization of the field of temperature and velocity distribution, as well as a vector distribution of gas flow rates. The obtained results of the computer simulation allowed evaluating the efficiency of the thermal and gas-dynamic performance of the developed design of the drum-type batch furnace with a constant temperature of the operating space. The developed design of the furnace for heating of metal billets with moving of billets in the furnace along the drum allows solving of some problems of resource and energy saving; it could also be used for heat treatment of bars, pipes, strip, and bar sections of various shapes.

Keywords: batch furnace with a constant temperature of operating space, recuperative burner, computer simulation, temperature fields, velocity fields, resource saving, burning, heat exchange

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1. Introduction

The designs of heating furnaces, used these days, have a significant number of disadvantages. The roller and traveling hearths are the most common ways of metal transportation in such furnaces. Heating roller furnaces, installed in the flow of rolling mills, have a long extension, so they are difficult to locate in the operating workshops.

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The drum-type batch furnace for heating of billets before hardening has been developed by the scientists of JSC 'RIMHE' along with the Department of Thermal Physics and Computer Science in Metallurgy of the Ural Federal University.

When implementing the proposed design with transportation of rolled products in the heating furnaces with a drum mechanism that significantly reduces the furnace dimensions, simplifying the transport mechanisms and not having water-cooled elements, a significant reduction of resource consumption could be expected. The design ensures a constant temperature in the operating space of the furnace due to drawing of heated metal in small portions. The billet passes its way into the furnace in thirty minutes, at the same time the new cold billet is loaded, and the hot billet is unloaded.

Recuperative burners of GSR-150 type, operating as follows, carry out the heating of metal products in the batch furnace: gas flows from the nozzle into the combustion chamber where it mixes with a part of air heated in the heat exchanger to a high temperature and burns partially in the combustion chamber. The remaining air is supplied through the annular gap between the nozzle of the combustion chamber and the end wall of the burner and burns the fuel in the furnace operating space, mixing with the products of incomplete combustion. The combustion products from the operating space are removed through the recuperators built into the burners into the fabricated metal, heat-insulated exhaust duct.

Schematically, the design of the heating furnace under consideration for hardening is shown in Figure 1.

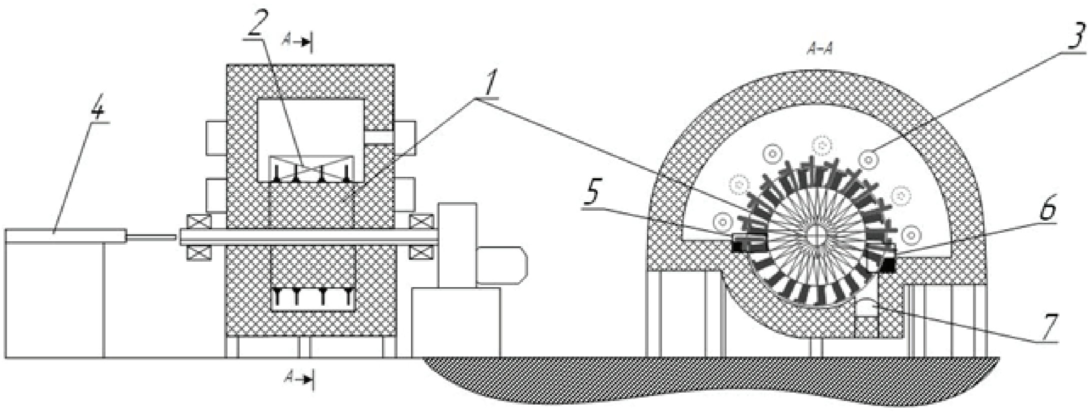


Figure 1: Schematic design of the heating furnace: 1 – drum with teeth; 2 – heated billets; 3 – fuel-burning devices; 4 – pusher; 5 – charging door; 6 – discharging door; 7 – oxide collection box.

The rotating drum carries out the transportation of rolled products during the heating process. The drum is made of nickel-based heat-resistant steel and is capable of long-term operation under stress at elevated temperatures without noticeable permanent deformation and damage.

The thermotechnical calculations include calculation of fuel combustion, metal heating, items of heat balance and specific fuel consumption [1–4].

As a result of calculation of the natural gas combustion, the volume of combustion products was calculated at α=1.05, which turned out to be equal to V_α = 10.94 m^3/m^3. As a result of calculation of the metal heating, the charge weight is G_m=522 kg, the specific capacity of the furnace is $P_{a.\pi}$.= = 135.348 kg/(m^2*h).

By the i-t diagrams, the balance combustion temperatures $(t_0^\sigma;t_\alpha^\sigma)$ are determined:

$$t_0^\sigma = 1940^\circ;\ t_\alpha^\sigma = 2000^\circ.$$

The temperature of combustion gases is determined by the formula t = $t_\alpha^\sigma \cdot \eta_{\pi Np}$ [7], where $\eta_{\pi Np}$ is the dimensionless pyrometric coefficient, recommended for the batch furnaces, equal to 0.58.

$$t = 2000{\cdot}0,58 \approx 1160^\circ,$$

The temperature of metal at the outlet from the furnace is 880 °C. The obtained design temperature of combustion gases at 280 °C exceeds the final temperature of the heated ingot. Therefore, the proposed technological process is feasible with the chosen fuel and conditions of its combustion.

The useful thermal stress of the hearth surface $q_{M.\pi.}$ is found out taking into account the increment in the heat content of metal during the heating time by formula

$$q_{M.\pi} = p_\pi * \Delta i_M,$$

where, p_π – specific capacity, kg/(m^2*h);

Δi_M – increment of the material enthalpy in the heating temperature range from $t_0$to t_M(τ), taking into account the average value of the specific heat of material c_M for the given interval. The value of the specific heat c_M =0.1645 kcal/(kg·°C) is taken from the reference [8] for steel Hadfield in the temperature range 20–880 °C. In this case, the heat stress $q_{M.\pi.}$ will be $q_{M.\pi.}$= 33685.67 W/ m^2.

The value of the heat stress of free space was found out taking into account the determination of the efficiency η of the furnace by formula

$$\eta = \frac{\Delta i_M}{7b},$$

where b – specific consumption of reference fuel, (kg r.f*t)/t.

$$\eta = \frac{214}{7 * 100} = 0,30571.$$

Thus, the value of heat stress, referred to free space of the operating space (without the burner channels), will be

$$q_\sigma = \frac{q_{M.\pi.}}{\eta * H_{\pi p}},$$

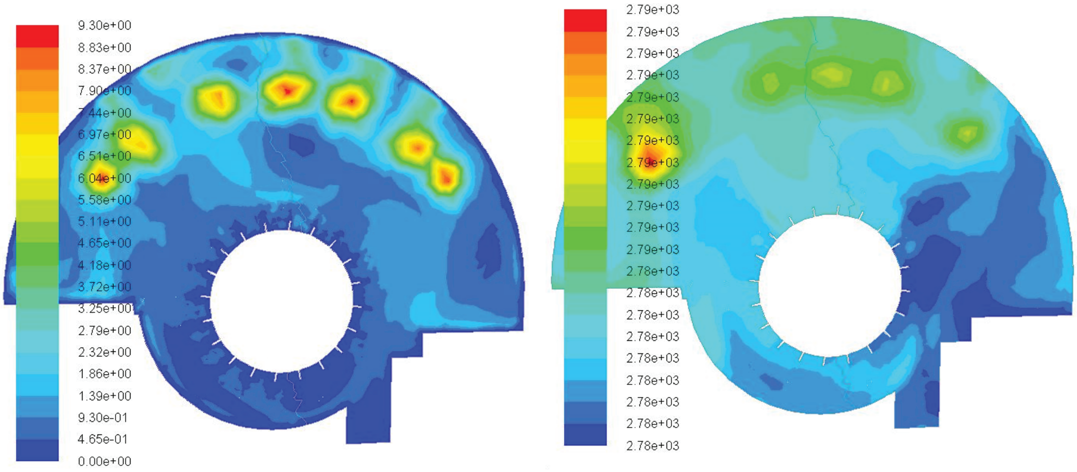
where $H_{\pi p}$ – maximum jet diameter, m.

$$q_\sigma = \frac{28964,47}{0,30571 * 0,727} = 130321,34 W/m^3.$$

Taking into account the jet length values (l_j = 3.175 m) and the furnace heat stress (q_σ = 130321.34 W/m^3), it is suggested to use recuperative burners GSR-150.

Using the CAE-system (Computer Aided Engineering) – the software module ANSYS Fluent, the simulation of distribution of gas velocities and temperature in the operating space of a drum-type batch furnace with a constant temperature of the operating space has been performed (Figure 2).

Having analyzed distributions obtained by the computer simulation method, it could be concluded as for the adequacy of parameters of the thermal and gas-dynamic conditions of the designed furnace structure and operation of burner devices. Figure 3 shows a fragment of the animated visualization of the vector distribution of velocity gas flows. The vector distribution of the velocity of gas flows in the zone of GRS-150 jets is shown in Figure 4. The graphs show that the maximum velocity of the combustion products at the nozzle outlet was 61 m/s, and the maximum burning temperature was 2241 °C. The performed studies will be used for the subsequent adjustment of the heating scheme in the furnace design.



a *b*

Figure 2: Distribution of temperature (a) and velocities (b) of gaseous combustion products in the furnace operating space.

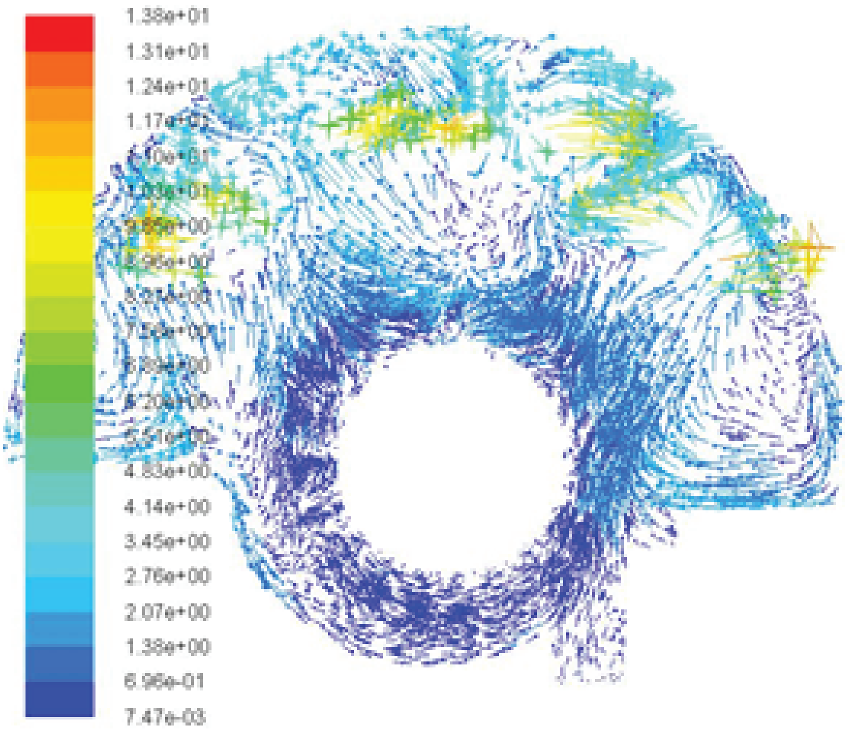
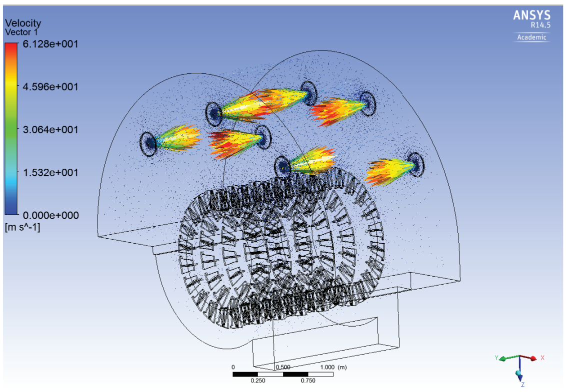


Figure 3: Vector distribution of velocity of gas flows in the operating space of the batch furnace.

2. Summary

Thus, as a result of the work, thermomechanical calculations of a drum-type batch furnace were performed in relation to the created designed structure. The obtained results of computer simulation allowed us to evaluate the efficiency of thermal and gas-dynamic performance of the developed design of a drum-type batch furnace with



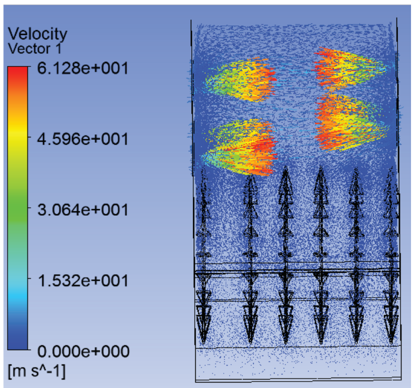


Figure 4: Vector distribution of velocity of gas flows in zone of GRS-150 jets.

a constant temperature of the operating space. The developed design and method of transportation of products in the furnace operating space could also be used for heat treatment of bars, pipes, strip, and bar sections of various shapes.

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