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ENERGY EFFICIENT WATER-COOLED ELEMENTS FOR FOUNDRY CLASS ELECTRIC ARC STEELMAKING FURNACES

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Introduction. Possibility of a wide choice of original charge and variation of oxidation potential in melting process makes the electric arc furnace (EAF) a general-purpose unit in foundries. Energy-intensive classical technology with insufficient specific power of the transformer, irregular operation with forced downtime predetermine a low energy efficiency of foundry class furnaces [1,2]. Flat and shallow bath of the EAF enhances the problem.

Mentioned doesn’t allow application of traditional for "large" metallurgy water-cooled elements (WCE) with one row tubes dense structure [3] due to technological risks, which causes heightened refractory consumption. A promising solution seems to be WCE with a spatial tubes structure (one row untight, two-rows), which is characterized by reduced by 25-35 % heat losses due to heat insulation and heat accumulation properties of deposit slag filling [4].

Known mathematical models of heat and mass transfer in the EAF workspace [5,6] don’t pay sufficient attention to the thermal state and energy loss in WCE.

The development of WCE with reduced heat loss and mathematical model substantiating optimal relative value of cooled surface in foundry class EAF are urgent.

Purpose is energy and refractory savings in the EAF due to WCE design improvement.

Method – mathematical and numerical modeling of thermal state of WCE in the EAF.

Research part. A mathematical model of heat exchange by radiation, adapted to the EAF conditions [7], was used. It deals with primary sources of radiation: bath surface, arcs and electrodes. The insignificant contribution of secondary radiation caused by dust and gas environment was not taken into account in the comparative analysis. Heat flow power (internal integral) emitting by surface F_{rad} (m^2) with temperature T_{rad} (K) per receiving surface of WCE F_{wce} (m^2) with temperature T (K) is, kW.

$$P_{wce} = k_{wce}\left(\sigma\varepsilon(T_{rad}^4 - T^4)\int_{F_{wce}}\iint_{F_{rad}}\left(\frac{\cos\theta\ \cos\gamma}{r^2}\right)dF_{rad}dF_{wce}\right) \qquad (1)$$

where σ – Stefan-Boltzmann constant, kW/(m^{2}K^4); ε – reduced emissivity of heat exchange surfaces; θ, γ, r – direction angles and radius vector, respectively; k_{wce} – averaging coefficient of the heat flux on surface of the WCE.

The emitting surface of arcs and electrodes is the lateral surface of the cylinders with electrodes pitch diameter. The arc length is approximated by the dependence from EAF capacity. The temperature of the bath surface, arc and WCE is taken 1820, 3550 and 1100 K, respectively. Electrode temperature is a function of relative height above the bath, [6].

Evaluations of (1) for 3-12-ton EAF are approximated by the multiple regression equation, obtained for relative from design considerations area of roof WCE 0.20-0.32, kW:

$$P_{wce} = k_{wce}\left(50.78M + 46.63m + 833.75\beta_w - 282.31\right) \qquad (2)$$

where M – EAF capacity, t; m - bath shape factor (diameter to depth ratio); β_w – relative area of walls WCE.

Two-dimensional problem of WCE thermal state in the EAF workspace was simulated in application package ELCUT 6.2 by the finite element method. Thermal fields in WCE under action of heat flux q are shown in Fig.1.

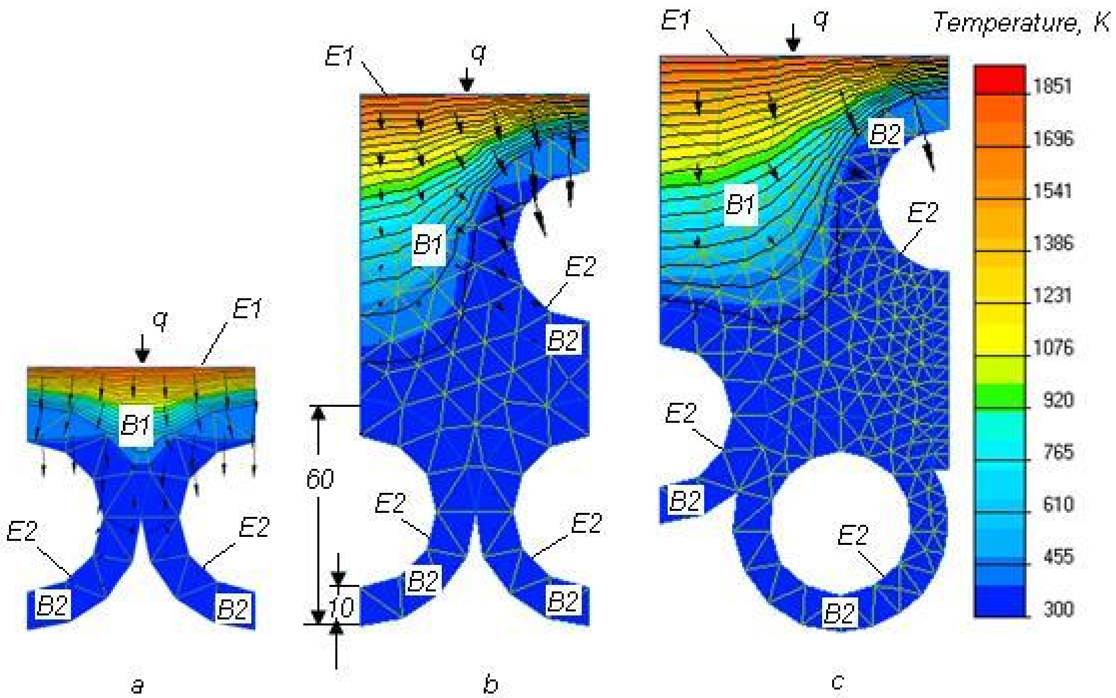

Figure 1 – Temperature fields in traditional (*a*), two-rows (*b*) and proposed three-rows (*c*) WCE. Lines are isotherms; arrows show heat flux value and direction. Designations are in the text

Integral heat loss with cooling water evaluated by means of package on edges E2. Energy loss through outer WCE surface was neglected. Relative values of heat loss with cooling water are presented in Fig.2.

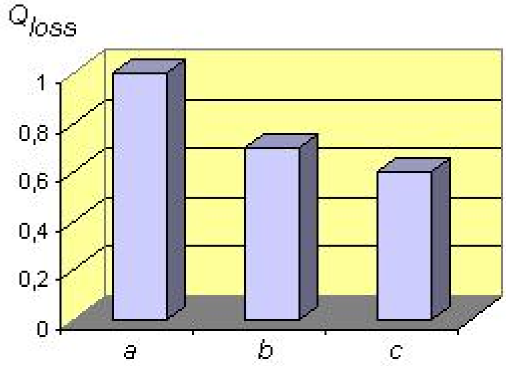

Figure 2 – Relative heat loss with cooling water Q_{loss} versus WCE options (*a, b, c*) according to Fig.1.

By analysis of heat flux, passing through the WCE working surface E1, the values of k_{wce} for panel options were obtained. For the proposed WCE an average relative cooled surface of walls in 3-12-t EAF can reach 0.5-0.6. Given value of β_w ensures reduction in refractory consumption up to 25-30 %. It derived from next conditions: melting of structural steel, forced bath inert gas stirring, reduction of bath shape factor from traditional 4.5 to 2.5.

Conclusion. Three-row water-cooled wall panels with a spatial structure are elaborated, which provide a decrease in heat loss by 14 %, in comparison with two-row ones, and by 40% in comparison with traditional one-row dense structure WCE. Estimates of optimal relative cooled surface of the EAF working space, providing refractory savings up to 25-30%, are substantiated.

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Abstract: Low energy efficiency of foundry class electric arc steelmaking furnaces (EAF) mainly is caused by heat loss by massive lining during forced downtime. A low-power transformer doesn't allow, in the conditions of classical technology, practice of traditional water-cooled elements in order to replace partially the lining, what determines increased refractory consumption. The aim is energy and refractory savings. On the basis of numerical modeling of heat exchange by radiation in the EAF working space, taking into account capacity, bath shape factor, duration of technological period of heat, a multiple regression equation for power of heat loss with cooling water was obtained. Three-row water-cooled wall panels with a spatial structure are elaborated, which provide a decrease in heat loss by 14 %, in comparison with two-row ones. Estimates of optimal relative cooled surface of the EAF working space, providing refractory savings up to 25-30%, are substantiated.

Keywords: foundry class electric arc furnaces, water-cooled elements, energy efficiency.