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Numerical Analysis of Temperature Distribution in Bottom Electrode of DC Arc Furnace in Process

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Abstract

Conducted comprehensive studies of the existing thermal bottom electrode (BE) in process. Considered separately BE coolant. The optimum parameters of copper BE (water-coolant, wall temperatures and geometric parameters) under specific operating conditions calculated.

Keywords: bottom electrode, Nusselt number, heat transfer, forced convective boiling, heat transfer

1 Introduction

Electric arc furnaces DC due to a number of technical and economic advantages [1] in front of furnaces AC received a significant spread in the engineering industry for the production of high-quality steels and alloys, and the "big" metallurgy [2] in the production of the precursor. Bottom electrode (BE) is one of the basic units of arc furnaces DC. The electrode is in conditions of high temperature. Interactions occur of high temperature fluid (melt) and the walls of the electrode material [3]. This leads to the erosion of the electrode and its subsequent failure and downtime. To reduce the rate of erosion is required to compensate the thermal effects by the current of cooling environment (water, etc.). One of the main tasks is to provide in the design heat transfer from the BE. One way of providing production efficiency of BE is a head made of steel with a high melting point and a water-cooled copper bottom portion [4, 5]. To improve heat transfer between the steel and the copper portion the contact area must be increased, by applying of ribs [6, 7]. However, the above solutions lead to a complicated construction and low efficiency of model.

In the course of solving this problem is usually, regarded cooling BE from the standpoint the theory of heat transfer. In which the transfer of heat from one medium to another through separating solid any form wall includes the heat transfer from the hot coolant to the cooler medium. Under given circumstances it is necessary to find the heat flow from the molten metal to the cooling water and wall surface temperature.

2 Materials and Methods

Measurements carried out during operation on a small furnace 250 kg (Fig. 1) for the smelting of pig iron. Operation parameters are: amperage 1900 A, voltage 83 V, melt temperature 1550^0 C, environment temperature 10^0 C. Cooling water temperature at the inlet of BE is 25^0 C, at the outlet 33^0 C, the water flow rate is 2 cbm per hour. During the work of this furnace by water-cooling with forced convective boiling realized.

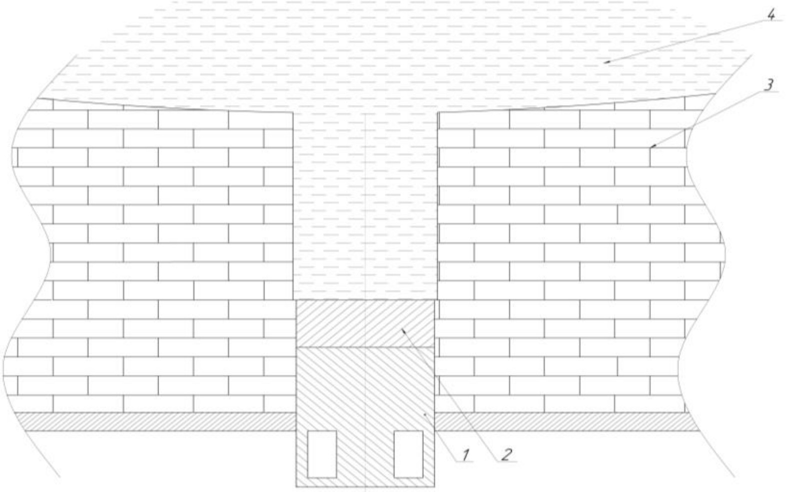

Figure 1: Furnace 250 kg

3 Analysis

Total thermal resistance is composed of partial thermal resistances $1/\alpha_1$, δ/λ, $1/\alpha_2$. Where $1/\alpha_1 = R_{FeCu}$ - thermal resistance of heat transfer from the hot fluid to the wall surface; $\delta/\lambda = R_{Cu}$ - thermal resistance of the thermal conductivity of the wall; $1/\alpha_2 = R_{CuH2O}$ - thermal resistance of the heat transfer from the surface of the wall to the cold fluid. The heat flow through the body is equal to [8]:

$$q = \frac{t_{l1} - t_{l2}}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}},$$

where t_{l1} - melt temperature t_{l2} – cooling liquid temperature (water), α - heat transfer coefficient, λ - thermal conductivity. Heat flux Q, through the surface F of solid wall equal to:

$$Q = q \cdot F$$

From the analysis of the thermal impedance R, must set the ratio of longitudinal and transverse dimensions of the BE, that is the ratio of contact area with the melt and a length of BE. To determine the heat transfer coefficients α1 and α2 is necessary to apply similarity theory.

The findings of the experiments are summarized by a system of similarity criteria. Results of experiments to determine the heat transfer coefficients α are as criterial equation [9]:

$$Nu = C \cdot \mathrm{Re}^m \cdot \mathrm{Pr}^n \cdot Gr^p$$

where Nu=α**l*/λ - Nusselt number; here *l* - the characteristic dimension, λ - thermal conductivity; Re - Reynolds number, Pr - Prandtl number, Gr - Grashof number.

4 Numerical Analysis

Boiling heat transfer associated with a change in the aggregate state. In a thin layer at the heating wall forced convective boiling occurs. Film boiling on the heating surface forms a continuous film of pair [9]. Film pair creates additional thermal resistance and reduces heat transfer. Is necessary to exclude film boiling, leading to the accident (damage and melting) of BE. Based on experimental data and using the theory of heat transfer on the counting temperature of copper BE on surfaces by melt and cooling water. Thus, we obtain the temperature drop at the electrode depends on thermal resistance. Let us consider all thermal resistances (Fig. 2).

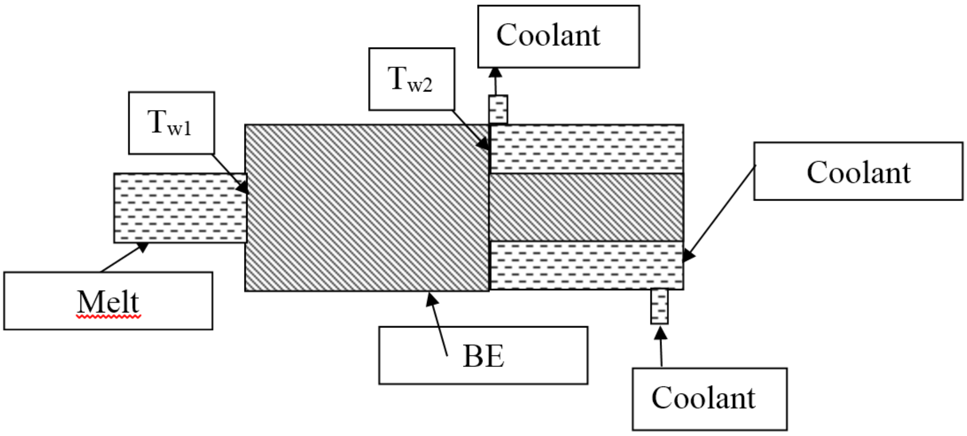

Figure 2: System "melt - BE - coolant (water)."

5 Thermal resistance during heat transfer "melt - BE" (R_{FeCu}).

Heat transfer of molten metal to BE is due to free convection. Dependence of Nusselt number for free convection with Gr and Pr is [10]:

$Nu = 0.105 \cdot \Pr^{n} \cdot Gr^{1/3}$

where n = $0.3+0.02/Pr^{1/3}$

If Gr> 10^9, then:

$Nu = 0.017 \cdot \Pr^{n} \cdot Gr^{1/3}$

where n = $0.3+0.02/Pr^{1/3}$

6 Thermal Resistance of BE (R_{Cu}).

Thermal resistance of BE is determined by the formula [9]:

$$R = F \cdot \frac{\delta}{\lambda}$$

where F - sectional area, δ - wall thickness.

During calculations also found, that the surface area of BE contact with the molten should be within 35-55% of the sectional area of BE. Which in turn allows more effectively remove heat to mass of metal and reduce the heat load on the electrode surface.

Thus, the cross-sectional area with increasing BE decreases thermal resistance.

7 Thermal Resistance "BE - Water" (R_{CuH2O}).

Heat transfer from BE to water is due to the forced convective boiling on the surface of BE, wich is calculated using Nusselt number [10]:

$$Nu = 0.035 \cdot \mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{0.4}$$

Using experimental data, temperature is calculated on the walls of BE at side of the melt and water T_{w1} T_{w2} (Fig.3) considering deposited power, weight and chemical composition of the melt.

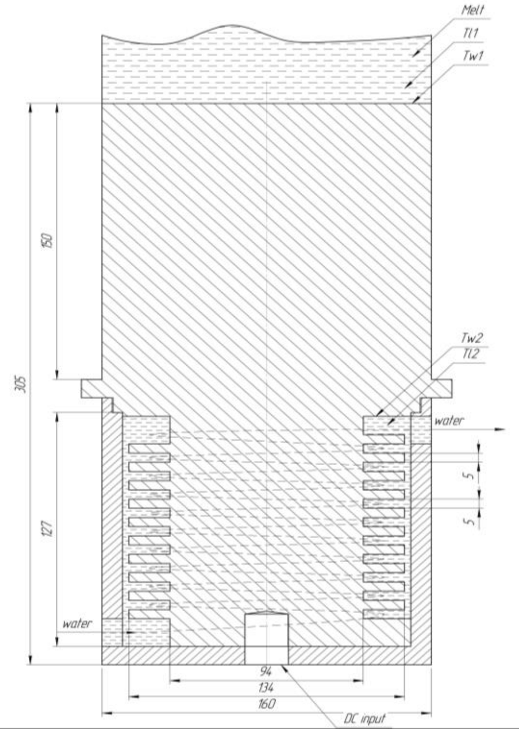

Figure 3: Recommended BE

Calculation carried out in PTC Mathcad v14.0 (license №PTC60602CD140.004 of 18.08.2008). Also, the temperature difference ΔT is given of a cooling liquid (water) between inlet and outlet of BE. Calculations where made for the furnaces at 250 kg and 500 kg used for smelting pig iron and ferromolybdenum, used for smelting iron. Data presented in Table 1.

Table 1 BE wall temperature value T_{w1} by a melt T_{w2} by a cooling liquid and the temperature difference ΔT of a cooling liquid (water) between inlet and outlet of BE.

Furnace	250 kg.		500 kg
Material	pig iron	ferromolybdenum	pig iron
R_{FeCu}, W/K	0,0177	0,0342	0,008
R_{Cu}, W/K	0,0350	0,0350	0,0190
R_{CuH2O}, W/K	0,0034	0,0034	0,0034
Tw1, ^{0}C	1016	1057	1086
Tw2, ^{0}C	119	123	193
ΔT ^{0}C	9	10	15

8 Results

To exclude the film boiling during BE operation proposed to apply spiral cooling channel with entry point of coolant at bottom of spiral, release at top, which allows to move generated bubbles upward by the cooling channel without delay bubbles to exit BE (Fig. 3).

In due to expected overheating BE recommended to increase the amount of heat withdrawn due to of creating ribbed surface at side of the coolant.

The ribs in cross-sectional profile can have the most different geometric configuration (a rectangle, a circle, a triangle, and other shapes, including geometric irregular shapes).

Figure 4 is a diagram of a cross-sectional rectangular rib. When calculating the dimensions of ribs important factor finning E_r is defined [9], according to the heat transfer coefficient α, the rib dimensions (R_1, R_2 and δ) etc.

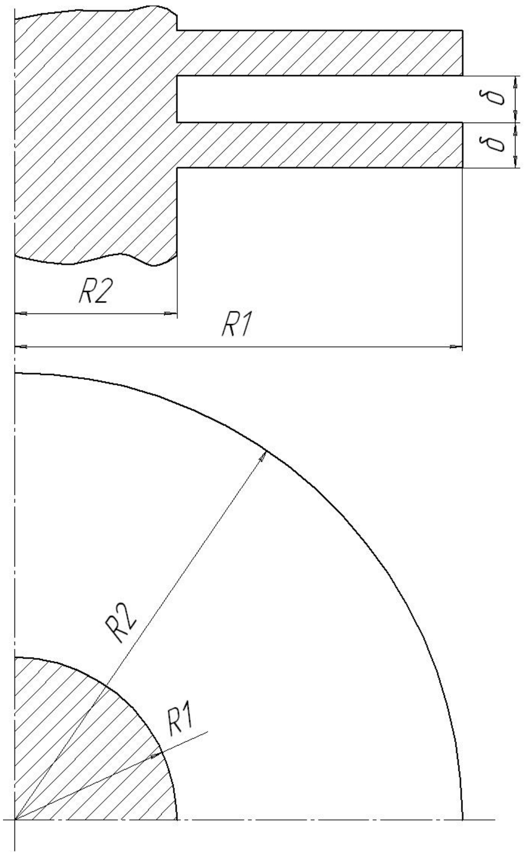

Figure 4: Diagram of a cross-sectional rectangular rib

Heat flux from finned surface determined by the formula [9]:
$Q= \alpha_2 * F_r * (T_w - T_l) * E_r$,
where F_r - finned surface
T_w, T_l – temperatures of a wall and liquid.

9 Conclusion

Vary of BE length is not recommended, as it is lead to an increase R_{Cu}, consequently, to an increase in the temperature difference on the BE surfaces T_{w1} T_{w2}. While from the melt temperature difference decreases, and as a result will increase the temperature T_{w1}. That lead to melting of BE and its subsequent failure. It is effective to change the contact area with the cooling liquid. In the context of the small size, the use of ribs BE is an exit.

Also from the calculations show that the application of steel head in BE would increase thermal resistance and a decrease in its lifetime.

Of paper it follows that modeling of thermal processes in BE is possible, that allowing the design of BE without the need for costly experiments.

Interesting application of the physical phenomena occurring in the furnace at its design [3]. Also, the use of mathematical modeling and design of intelligent control systems [11, 12]. This will greatly increase the life and productivity of the furnace.

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