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Calculation of Thermal Processes in Bottom Electrode

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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. Drawn up formulas and graphs to determine the optimum geometrical parameters of BE under different operating conditions.
Calculation and simulation of BE in process are held.

Keywords: bottom electrode, Nusselt number, heat transfer, thermal resistance

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 heat. 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, by form of BE, heat transfer from BE. One of the solutions 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 Analysis

Total thermal resistance is composed of partial thermal resistances $1/\alpha 1$, δ/λ, $1/\alpha 2$. And $1/\alpha 1 = RFeCu$ - thermal resistance of heat transfer from the hot fluid to the wall surface; $1/\alpha 1 = RFeCu$ - thermal resistance of the thermal conductivity of the wall; $1/\alpha 2 = RCuH2O$ - 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).
Heat flux Q, through the surface F of solid wall equal to:

$$Q = q \cdot F$$

To determine the heat transfer coefficients α1 and α2 is necessary to apply the 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]:
$Nu=CRe^{m}Pr^{n}Gr^{p}$,
where Nu=α*l/λ - Nusselt number; here α - heat transfer coefficient; *l* - the characteristic dimension; λ - thermal conductivity, Re - Reynolds number, Pr - Prandtl number, Gr - Grashof number.
During the next calculation proposed BE design (Fig.1):

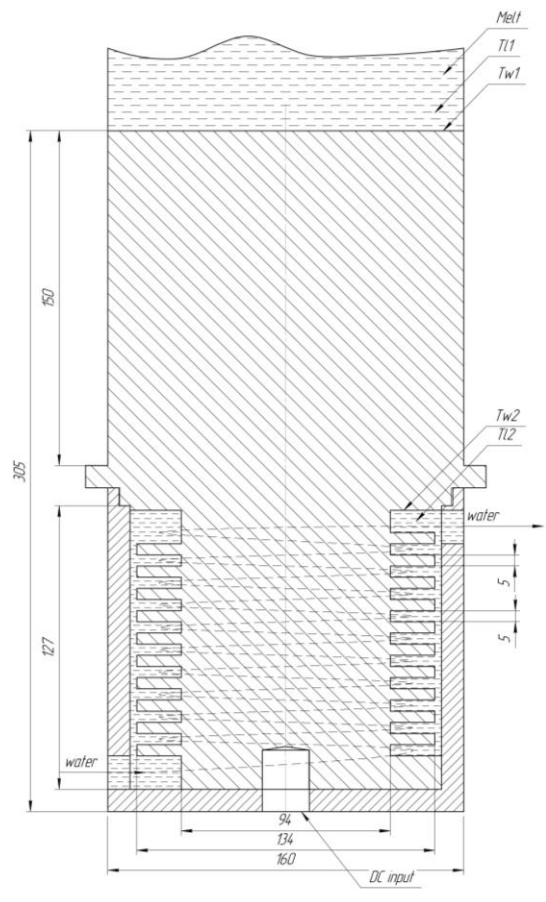

Figure 1: Recommended design of BE

3 Calculation

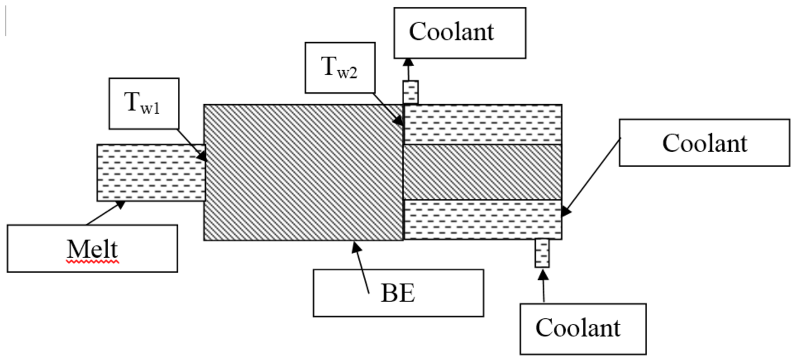

Figure 2: System "melt - BE - coolant (water)".

Consider system "melt - BE - coolant (water)".
It is necessary to determine the thermal resistance and the temperature distribution (Fig. 3) [10].
Imagine the thermal resistance as the series connection of resistors. The calculation was performed in PTC Mathcad v14.0 (license №PTC60602CD140.004 of 18.08.2008).

R_{FeCu}=1,794*10^{-4} W/(K*m^2) S_1=0,008 m^2

R_{Cu}=4,286*10^{-4} W/(K*m^2) S_2=0,018 m^2

R_{CuH2O}=2,346*10^{-4} W/(K*m^2) S_3=0,16 m^2

Figure 3: Thermal resistances attributed to 1m^2.

After recalculation to their actual size (Fig. 3), obtain:
R_{FeCu} =229,3*10^{-4} W/K, R_{Cu} =243,5*10^{-4} W/K, R_{CuH2O} =16,7*10^{-4} W/K.
Value of temperature, at a differential in 2000^{0}C at this point in the system "melt - BE - coolant (water)" will match the ratio of the total resistance to the resistance at this point Rx (Rx assume the temperature of the melt cooling) (Fig. 4)

$T=T_{Fe}-(T_{Fe} - T_{H20}) *Rx/(R_{FeCu} + R_{Cu} + R_{CuH2O})$
Tw1=2000^{0}C -1970^{0}C * R_{FeCu} /(R_{FeCu} + R_{Cu} + R_{CuH2O})=2000^{0}C -1970^{0}C * 229,3/(229,3+243,5+16,7)=1077^{0}C

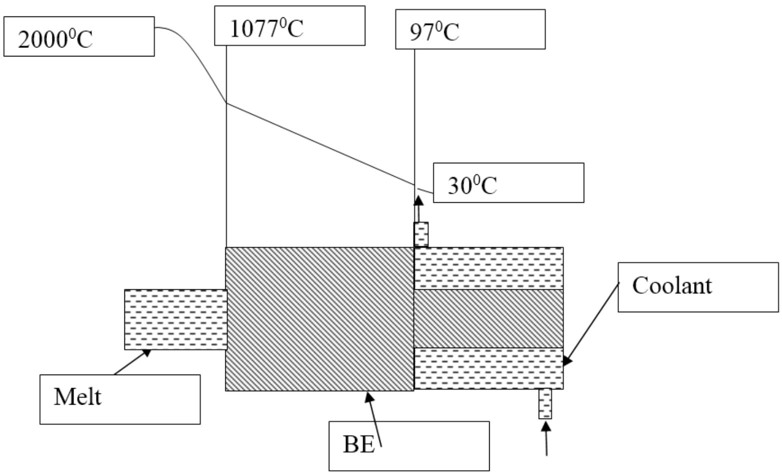

Figure 4: System "melt - BE - coolant (water)."

Graphs, obtained after calculations in MathCAD, showing the relationship of heat flow Q, diameter d of BE and melt temperature T (Fig. 5).

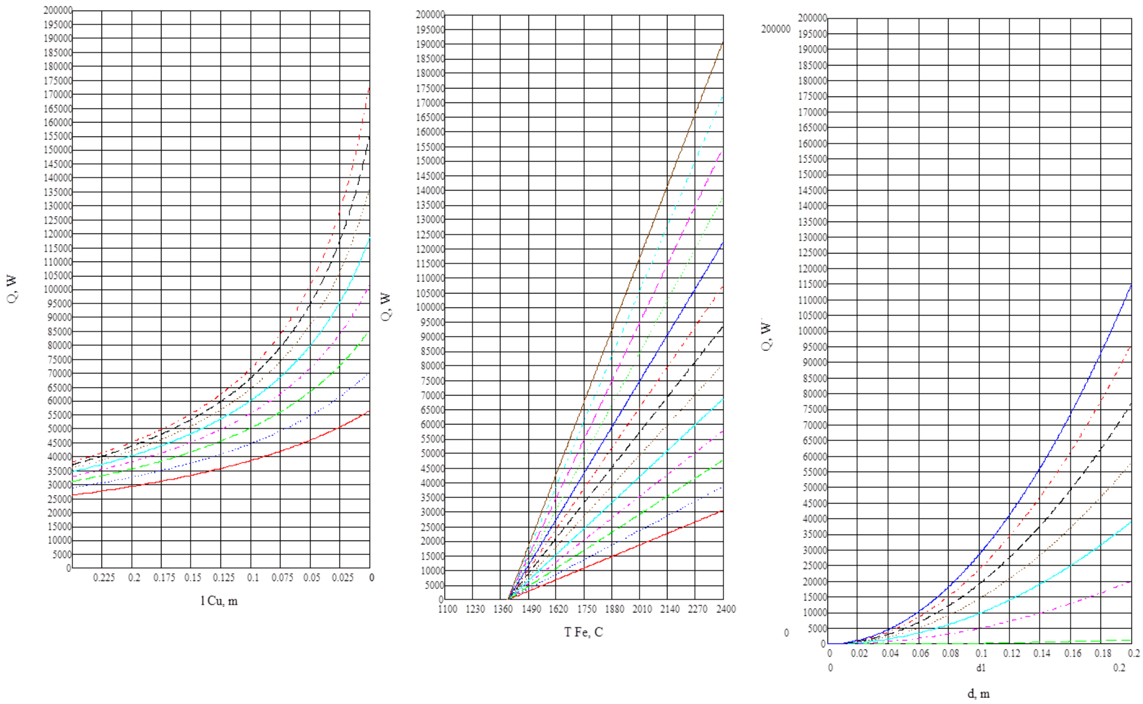

Figure 5: Graphs of the critical heat flow as a function of the diameter of contact with the molten BE, BE length and temperature of the melt.

These graphs (Fig. 5) are plotted for the proposed structure of BE (with a defined number of ribs, size of the fins, the flow cross section area) and the flow of coolant (water) 2 cbm per hour

Computer simulation in Star-CCM shows temperature distribution of BE in process (Fig. 6). Simulation is made for melt temperature 2000°C. All data taken from calculations.

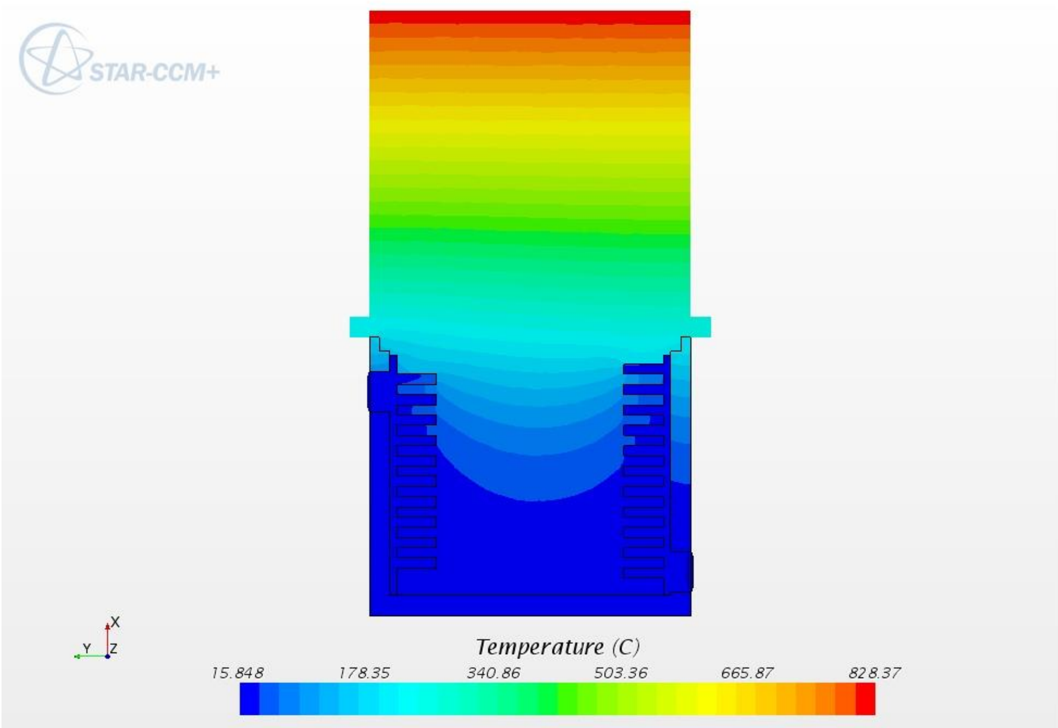

Figure 6: Computer simulation of temperature distribution.

Results of calculations compared with numerical analysis, calculations on various software packages and experimental data on the increased wear of the BE. Good agreement of data obtained in different ways, says the reliability of the results of computer simulation.

Analysis of the results of computer simulation of BE in metallurgical furnaces allowed suggesting methods to reduce the wear rate of the bottom electrode, and offer recommendations for optimizing the operation of the furnaces

4 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.
The resulting model would achieve the required BE size and working capacity without the need for costly experiments.
Interesting application of the physical phenomena occurring in the furnace at its design [3, 10]. 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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References

[1] V.S. Malinovskiy, V.D. Malinovskiy, L.V. Yarnih, A.V. Afanaskin: *Russian Ironshaper*. 2002, №1, pp. 24-27.

[2] Y. Toulouevski, I. Zinurov: *Innovation in Electric Arc Furnaces*, p. 258, Springer-Verlag, Berlin Heidelberg, 2010. http://dx.doi.org/10.1007/978-3-642-03802-0

[3] O. Kazak, O. Semko: *Ironmaking Steelmaking,* 2013, Vol. 40, Issue 8, pp. 619-624. http://dx.doi.org/10.1179/1743281212y.0000000081

[4] Pat. US 5233625 (1993)

[5] Pat. RU 2061998 (1992)

[6] Pat. US 5651024 (1997)

[7] Pat. RU 2285356 (2004)

[8] S. S. Kuteladze: *Heat transfer and flow resistance: Handbook*, p. 367, Energoatomizdat, Moscow, 1990.

[9] H. Uong: *Basic formulas and data on heat transfer for engineers. Handbook,* p. 416c, Atomizdat, Moscow, 1979.

[10] O. Kazak, O. Semko: *Ironmaking Steelmaking*, 2011, Vol. 38, Issue 5. pp. 353-358.

[11] Simonova L., Israphilov I., Israphilov D., Chernova M. Mathematical simulation of intelligent control system of metal vacuum sputtering process on the

basis of application of multi-agent system. World Applied Sciences Journal. Volume 23 Number 7, 2013 930-934p.

[12] Simonova L., Nugumanova A., Israphilov D., Chernova M. Intelligent control system of metal vacuum sputtering process on the basis of application of multi-agent system World Applied Sciences Journal. Volume 23 Number 7, 2013 926-929p.

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