ANALYTICAL MODEL OF RADIATIVE HEAT TRANSFER IN ELECTRIC ARC FURNACE

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INTRODUCTION

Nowadays, electric arc furnaces (EAF) are used in steel plants both for melting and overheating of metals to a determined temperature over the melting point temperature (the liquidus), and for the metallurgic processes of refining and alloying. There are alternating current electric arc furnaces (AC EAF) and direct current electric arc furnaces (DC EAF). In conventional AC EAF, the material (scrap) is melted by electric arcs which establish between the tip of electrodes and scrap charged into the furnace. DC EAF is basically characterised by a single, centrally-located graphite electrode acting as a cathode, and by several bottom electrodes acting as anodes, Fig. 1. Thus, along with electrodes, the most important part of EAF is the space (the bath) manufactured by refractory bricks, in which the melting process occurs. Over bath, the wall and roof panels are located. Today, in ultra high power EAF, water-cooled wall and roof panels are usually used, Fig. 2. The previously used panels, lined with refractory brick, are modified today so that more than 90% of all furnaces are equipped with water-cooled panels. Various types of panels and different conditions during exploitation require serious analyses of heat transfer mechanism inside EAF, especially radiation. The poster presents the developed analytical model of radiative heat transfer in EAF - appropriate tool in designing new water-cooled panels, which can maintain a stable layer of slag on their surface as an insulator in all working conditions, at the same time minimising cooling water consumption, heat losses and increasing reliability and duration.

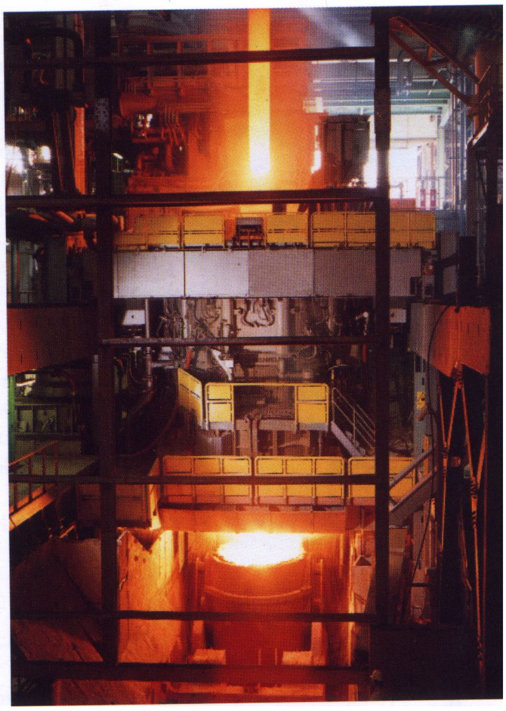

Fig. 1 Working sequence of DC EAF

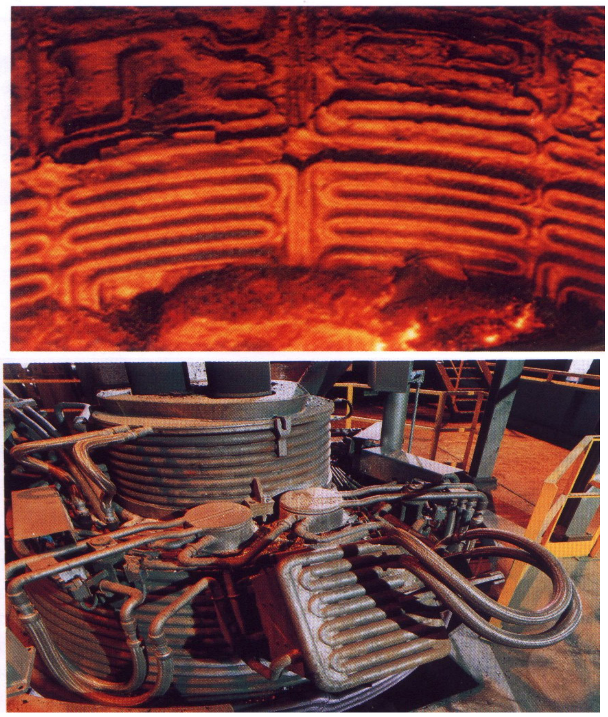

Fig. 2 Water-cooled wall panels coated with a stable layer of slag (over) and roof panels (below)

DESCRIPTION OF THE MODEL

The radiative heat transfer has the major effect in single phases of the melting process inside EAF, especially in the final melting period and during the overheating of the melt to the required tapping temperature. Similarly, the presence of water-cooled wall and roof panels changes state of heat transfer in EAF: heat transferred by radiation to panels is further transferred by conduction and convection on the cooling water. The result is a significant amount of heat which is rejected from furnace: it is therefore important to maintain a stable layer of slag on panel surfaces as heat insulator. The performed calculations have shown that heat transfer by convection inside EAF can be neglected. The portion of total heat flux falling on the wall and roof panels is due to radiation about 95%. This indicates that radiation heat transfer is the main mechanism of heat transfer in EAF.

The presented model includes the following radiative heat fluxes: 1) radiation from the electrode to the wall and roof panels; 2) radiation from the electric arc to the wall and roof panels; 3) radiation from the slag/melt to the wall and roof panels; 4) radiation of the gas to the wall and roof panels.

In spite of the fact that today radiative heat transfer can be calculated by means of numerical modelling, the analytical solutions are still widely used. The analytical model of multidimensional and complex geometry such as EAF is set for the reason of its transparency: it is possible to determine and analyse separately the radiative heat fluxes between surfaces of electrode, slag/melt, electric arc and wall or roof panels for tap to tap time.

The model is based on fundamental equations for radiative heat transfer[1]. The amount of radiation heat $Q_{1\text{-}2}$ transferred from surface A_1 with temperature T_1 to surface A_2 with temperature T_2 is calculated by equation:

$$Q_{1-2} = C_c \varepsilon_{1-2} \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \varphi_{1-2} A_1 , \tag{1}$$

where: C_c= 5,67 W/m^{2}K^4 – Stefan-Boltzman constant; $\varepsilon_{1\text{-}2}$ – emissivity of two-surface (A_1 and A_2) enclosure; $\varphi_{1\text{-}2}$ – angle factor between surfaces A_1 and A_2.

The single expressions for angle factors φ are obtained by means of equations for the elementary geometrical configurations from the angle factor catalogue and by means of the angle factor algebra[1]. In spite of the fact that the furnace geometrical model is represented by simple form such as cylinder, circle, ring, etc., the obtained expressions for view factors are rather complex. The single expressions for emissivity $\varepsilon_{1\text{-}2}$ are obtained according to the general equation for the two-surface enclosure[1]:

$$\varepsilon_{1-2} = \frac{1}{1 + \left(\frac{1}{\varepsilon_1} - 1 \right) \varphi_{1-2} + \left(\frac{1}{\varepsilon_2} - 1 \right) \varphi_{2-1}} , \tag{1a}$$

where: ε_1, ε_2 - emissivity of surfaces A_1 and A_2. The single expressions for view factor and emissivity of two-surface enclosures are presented in the table on the poster.

Radiation flux from the gas within EAF (mixture of CO_2 and H_2O) to the panel surface is calculated by equation[1]:

$$q_{g-p} = \varepsilon_p C_c \left[\varepsilon_g \left(\frac{T_g}{100} \right)^4 - a_g \left(\frac{T_p}{100} \right)^4 \right]. \tag{2}$$

The emissivity and the absorptivity of the gas (ε_g i.e. a_g) are calculated by the equations[1]:

$$\varepsilon_g = \varepsilon_{CO_2} + \beta \varepsilon_{H_2O} - \varepsilon_{CO_2} \varepsilon_{H_2O}; \tag{2a}$$

$$a_g = a_{CO_2} + a_{H_2O} - a_{CO_2} a_{H_2O}; \quad a_{CO_2} = \varepsilon'_{CO_2} \left(\frac{T_g}{T_p} \right)^{0,65}; \quad a_{H_2O} = \varepsilon'_{H_2O} \left(\frac{T_g}{T_p} \right)^{0,45}. \tag{2b,c,d}$$

In previous equations: T_g, T_p – temperature of the gas i.e. of panel surface; ε_p - emissivity of the panel surface; $\varepsilon_{CO_2}, \varepsilon_{H_2O}$ – emissivity of CO_2 and H_2O determined on the basis of T_g; $\varepsilon'_{CO_2}, \varepsilon'_{H_2O}$ - emissivity of CO_2 and H_2O determined on the basis of T_p; β - correction factor.

The figures on the poster presents the some results of calculations of radiative heat fluxes distributions from electrode, electric arc, slag/melt and gas along wall and roof panels, both in AC EAF and in DC EAF. All calculations are programmed in a tabular calculator on PS. The presented results are based on geometrical, mechanical and thermal values which are common in EAF technologies.

CONCLUSION

New demands for high efficiency in steelmaking (decrease of tap to tap time, reduction of electrical melting power, electrode and cooling water consumption, etc.) require different and new approaches in EAF design. The presented analytical model for determining the radiative heat transfer in EAF provides results acceptable for engineering applications, and they can be used in complete analysis of the existing and in design of new water-cooled panels in high power EAF[2]. In its application in designing new water-cooled roof and wall panels[3-4], the energy losses due to heat flux into cooling water are drastically reduced while at the same time greatly increasing the panel duration.

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