Effect of Atmospheric Smoke and Slag Height on Heat Exchange In Arc Steel Smelting Furnaces. Part II. Effect of Slag Height on Heat Loads and Energy Consumption

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Abstract

The effect of the height of slag layer on heat loads on water-cooled panels of the walls of arc steel smelting furnaces was investigated. The fluxes of heat radiation from arcs to water-cooled wall panels are maximum when the arcs are not deepened and the atmosphere of the furnace is transparent. With the increase of slag layer height and the absorptive capacity of dust and gas furnace atmosphere, the heat loads from arcs on the water-cooled wall panels decrease and reach a minimum, when the arcs are completely immersed in the slag and the absorption coefficient of dust and gas furnace atmosphere reach a maximum.

Keywords: Electric Steel, Electric ARC, Heat Exchange, Thermal Radiation, Furnace

1) INTRODUCTION

Electric arcs are the main heat energy sources in arc steel smelting furnaces (ASF), they accounted for 55–65 per cent of heat energy supplied to a modern ASF [1–13]. To reduce the consumption of electrical and heat energy, it is necessary to organize the operating mode of the ASF arcs in such a way that the heat flux of radiation from the arcs maximally reaches the metal charge and metal bath and minimally to the lined slopes, water-cooled panels of walls and arch. The heat flux of arcs in ASF consists of 92–96% of the heat radiation flux, while heat conduction and convection fluxes account for 4–8% of the power [3–5] according to long-term pilot studies of research teams [1–7].

In the twentieth century, there were no data from an analytical study of the distribution of heat fluxes of radiation from arcs over the surface of walls, arch, metal bath. At the end of the twentieth century, the author of the article developed a pioneering theory of heat transfer in ASF [1], which allows calculating the heat fluxes of radiation from arcs on the surface of walls, arch, metal bath. The method for calculating heat transfer is described in detail in [1, 2], we will use it to analyze the effect of the height of slag layer on heat loads from arcs on the water-cooled wall panels and on the specific power consumption in arc steel smelting furnaces.

2) CALCULATION OF HEAT RADIATION FLUXES OF ARCS ON THE WALLS OF ASF

The scheme for calculating fluxes of heat radiation from arcs on the water-cooled panels of the walls is shown in Figure 1.
Significant heat loads on the water-cooled wall panels cause damage to the panels, water leakage from the damaged panels to the metal bath, which is an emergency. The calculations of heat flows of arcs to water-cooled wall panels in high-power arc steel smelting furnaces ASFS-100 with a 100 ton capacity, 90 MVA transformer should be performed. We need to figure out what the maximum value of heat radiation fluxes of arcs on the water-cooled wall panels is, how the absorptive capacity, the absorption coefficient of dust and gas medium affect the heat flows rate of radiation from arcs on the walls. Need to find out how the height of the slag layer affects the heat flows of arc radiation on water-cooled wall panels. Here are the parameters of each of the three arcs of ASF-100: $P_a=18$ MW, $l_a=300$ mm, $\alpha_{rad}=0.92$. The absorption coefficient $k = 0$ is for ray-transparent atmosphere, $k = 0.7$ is for dust atmosphere of the furnace.

3) **EFFECT OF SLAG LAYER HEIGHT ON HEAT LOADS ON WALLS AND ARC EFFICIENCY**

To increase the height of the slag layer to 250-350 mm, it is necessary to intensify the operation of the coal powder injector, while removing the maximum volume of the dust and gas mixture from the furnace (Figure 2).
Heat radiation flows of arcs on the walls of the ASF-100 were calculated when deepening arcs in a metal bath and slag by 300 mm. Since the length of the arcs is 300 mm, therefore, they are completely immersed in the bath of metal and slag, the results are shown in Figure 3.

Figure 3. Distribution of densities of heat radiation flows of 300 mm high arcs, along the height of ASF-100 walls at 300 mm depth height of arcs in transparent atmosphere of the furnace (I), in absorptive atmosphere of the furnace (II) along the sections of walls located opposite the arc (a) and between the arcs (b).

With arcs completely immersed in slag, the maximum flows of heat radiation from arcs to wall sections located opposite the arcs are 300 kW/m² in transparent medium and 230 kW/m² in absorptive medium, which is 2-1.6 times less than the operation of an open arc furnace when they are deepened in a metal bath by 70 mm.

The heat loss with the cooling water is proportional to the heat flows incident from the arcs on the water-cooled panels. Thus, when the heat flows of the arcs on the walls decrease by 2-1.6 times, the heat loss with cooling water decrease similarly by 2-1.6 times and the useful heat flows of the arcs on the metal bath and slag increase by this same value, the efficiency of the arcs increases, and the specific power consumption of the furnace decreases.
The results of calculating the efficiency of arcs of ASF-100 furnace show [14 to 16] that when deepening arcs in a metal bath and slag from 70 to 300 mm, the efficiency of the arcs increase from 0.46 to 0.74, that is, 1.61 times. It is known, that arc efficiency is the ratio of the net arc power radiated by the arc column to the metal bath and the slag to the arc power. It is known, that the higher the height of the arc column not deepened in a metal bath and slag, the lower the arc efficiency [14-16]. Plasma arc furnaces have the lowest efficiency of arcs, their arc column is completely open and radiates up to 80% of the power into the free space, and about 20% of the power to the metal bath (Figure 4).

Efficiency of plasma-arc furnaces is 20-25% [1].

The results of calculation of heat radiation flow densities of arcs on walls ASF-100 walls are confirmed by practice of ASF operation. With increasing the height of the slag layer from 238 to 325 mm in ASF-120 furnace, the shielding of heat radiation from the arcs on the water-cooled panels of the walls and arch improved, the flows of heat radiation from the arcs on the metal bath, slag increased, the efficiency of the arcs increased, and the specific consumption of electricity decreased by 22% [17]. Similar data on increase in heat absorption of arcs by metal bath 1.5-1.8 times with increase in slag layer height to complete deepening of arcs into slag are given in [18.19]. Thus, the calculated, Figure 3, and experimental data [17-19] are in full agreement with each other; with an increase in the height of the slag layer on the operating furnaces, the flows of heat radiation from arcs on the walls decreased, flows of heat radiation from arcs on the metal bath, slag, heat absorption of metal bath, efficiency of arcs increased, specific power consumption decreased.

4. CONCLUSION

From the analysis of the energy balances of steel melts in ASFs, it follows that during the purging of the bath with oxygen and the operation of the coal powder injector for foaming the slag, dust and gas atmosphere of the furnace is characterized by the maximum absorption coefficient. At the maximum absorption coefficient of the dust and gas atmosphere of the furnace, the thermal radiation of the arcs into the free space of the furnace is absorbed by the dust and gas atmosphere of the furnace.

At the maximum absorption coefficient, the dust and gas atmosphere of the furnace shields the water-cooled panels of the walls and roof from the heat radiation from arcs, while heat losses with exhaust gases are maximum, with cooling water they are minimal.

In the absence of purging the bath with oxygen and when the coal powder injector is inoperative, the furnace atmosphere is radiant, the heat radiation from arcs freely passes through the free space of the furnace and falls on the water-cooled panels of the walls and roof. With a radiant furnace atmosphere, the heat loads on the water-cooled wall panels reach maximum values of 600 kW/m² and above. The period of operation with the radiant atmosphere of the furnace is the most dangerous, the most heat-stressed for the panels of the walls and the roof of the furnace. With a radiant furnace atmosphere, heat losses with cooling water are maximal, with flue gases they are minimal.

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Heat fluxes incident on the water-cooled wall panels are maximum in a radiant environment and when arcs slight deepening in slags reach 600 kW/m² and more. With an insignificant height of the slag layer, the efficiency of the arcs is small and amounts to 0.46, heat absorption of arcs by the bath is small, and the power consumption is increased. With full deepening in the slag, the efficiency of the arcs reach a value of 0.74-0.78, the heat absorption of the bath is maximum, and the specific power consumption decreases.

**NOMENCLATURE**

- q: density of heat radiation flux, kW/m²
- P: power, kW
- k: absorption coefficient of gas medium

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