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NUMERICAL SIMULATION OF ENERGY-EFFICIENT SOLUTIONS OF STEEL MELTING BATH WITH REGARDING KINETICS OF DESULPHURIZATION UNDER PNEUMATIC STIRRING IN THE ARC FURNACE OF FOUNDRY CLASS

ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ЕНЕРГОЕФЕКТИВНИХ РІШЕНЬ СТАЛЕПЛАВИЛЬНОЇ ВАННИ ЩОДО КІНЕТИКИ ДЕСУЛЬФУРАЦІЇ ПРИ ПНЕВМАТИЧНОМУ ПЕРЕМІШУВАННІ В ДУГОВІЙ ПЕЧІ ЛИВАРНОГО КЛАСУ

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State of the art. The post-war reconstruction of the steelmaking complex of Ukraine in context of the EU Green Course involves a gradual (by 2050) transition to mini-mills [1]. Such plants are a global trend in the introduction of low-carbon technologies due to use of electricity for steel smelting in the arc (EAF) or induction furnaces and, in the future, hydrogen as a reducer of iron-containing oxides by means of a solid-phase process.

A certain share of Ukrainian mini-mills should focus on low-volume metal products for local needs. It is rational to create such enterprises at machine-building plants by attracting small capacity EAF of the foundry class, which are idle due to reorientation of sales markets. Because of low specific power of the transformer (up to 0.4–0.5 MVA/t), the specified furnaces in the conditions of the mini-mill require modernization in the direction of increasing energy efficiency.

One of the concepts of the foundry class EAF modernizing [2] in the conditions of existing infrastructure, in particular the transformer, includes the introduction of a "deep" bath with a reduced form factor ω = D_b /H_b (ratio of diameter D_b to depth H_b). The other [3] consists in reducing the bath capacity at a given depth and the furnace productivity with a certain decrease in ω.

Both solutions involve forced mixing of the bath by purging with argon through a porous plug in the bottom center. The two-phase region formed during purging, due to the difference in densities with the main volume of the bath, is the driving force of circulation and acceleration of heat and mass exchange processes.

Tasks of research. Taking into account the possibility of using classical technology in the EAF for smelting of low-volume metal products with a long refining period, it is of interest to compare the kinetics of steel desulfurization, as a factor determining the melting time, in basic and "deep" baths.

Research. The duration of desulfurization τ_{des} (min.), according to [4], is determined by initial [S_0] and ultimate [S] sulfur content in steel (%), the sulfur distribution coefficient between slag and metal L_S and specific mixing power N_{mix} (W/ton). At given EAF capacity M (ton) and consumption coefficient of slag forming materials relative to the mass of steel k_{sl} (function of [S_0], [S], L_S) it constitutes:

$$\tau_{des} = \ln[([S]/[S_0])(1+\varepsilon_1)-\varepsilon_1]/(\varepsilon_2\cdot\varepsilon_1\cdot 60), \quad (1)$$

where $\varepsilon_1 = [1/(L_S k_{sl})]$, $\varepsilon_2 = -0.031 N_{mix}^{0.25}$.

The parameter N_{mix} for a steel melting bath with a depth of H_b (m) under the conditions of a bubble purging regime is determined by the work of isothermal expansion of the gas blown into the bath with a flow rate Q_0 (Nm^3/s) [5].

$$N_{mix} = Q_0\cdot\rho_g\cdot R\cdot T_m\cdot ln\,(1+H_b/1.48)/\left(M\cdot\mu_g\right), \quad (2)$$

where R – universal gas constant (J/(kmol·K)); ρ_g – gas density (kg/Nm^3), μ_g – molecular mass of gas (kg/kmol); 1.48 – hydrostatic depth of liquid steel (m).

Under the conditions of a real jet-bubble purging mode with argon consumption in operating conditions Q (m^3/s), a more acceptable expression for estimating the mixing power N_{mix}^* (W/ton) seems the following:

$$N_{mix}^* = u_m(1-\varphi)V^*\cdot\rho\cdot g/M, \quad (3)$$

where $u_m = 4.5\cdot Q^{0.33} H_b^{0.25}/(0.5D_b)^{0.33}$ – average steel velocity in two-phase region (m/s) [6]; $\varphi = n_b V_b/V^*$ – gas content ratio of two-phase region; V^* – volume of two-phase region (m^3); ρ – liquid steel density (kg/m^3), g –

acceleration due to gravity (m/s^2); $n_b = [Q \cdot (H_b/u_b)]/V^*$ – number of bubbles in two-phase region; V_b – average bubble volume (m^3); u_b – average bubble velocity (m/s).

Data concerning V_b, u_b, opening angle of the two-phase region (definition of V^*), necessary for the assessment of N_{mix}^* and τ_{des}, accepted according to [5–7].

Numerical studies carried out for 12-tons EAF. For the basic and "deep" bath ω = 4.5 and ω = 2.5, respectively. In the bath of reduced capacity ω = 2.5 at M = 6 tons. The shape of bath is cylindro-spherical with a height ratio of 1. In a such bath, D_b, H_b are related by equation: $(M/\rho) - [\pi(D_b/\omega)^3/16](1/3) + 3[D_b/(D_b/\omega)]^2 = 0$. Technological heat parameters are the following: [S_0] = 0.05%, [S] = 0.02%, content of CaO in slag 45 %, L_S =45 [7], porous plug diameter 60 mm, open porosity 0.3.

Results are represented in a Fig. 1, 2. Differences in definition of N_{mix} and N_{mix}^* (Fig. 1) consist in the presence of an optimal argon flow rate for given bath from the positions of maximum N_{mix}^*, which is reflected in the estimation of τ_{des} (Fig. 2).

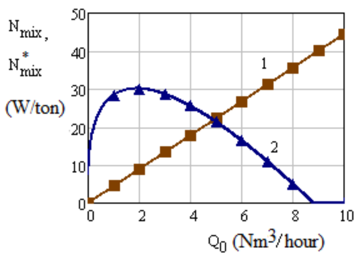

Fig. 1. Mixing power N_{mix} (1) and N_{mix}^* (2) versus argon purging flow rate Q_0

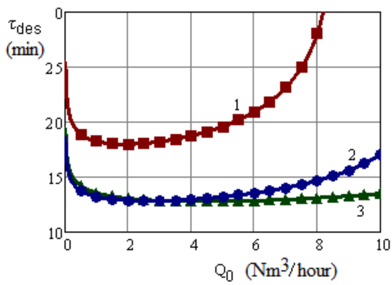

Fig. 2. Desulfurization time τ_{des} versus argon purging flow rate Q_0 in base (1), "deep" (2) and reduced (3) bath

Conclusions. Numerical modeling of the kinetics of steel desulphurization, taking into account energy-efficient solutions of a "deep" steel melting bath of the EAF of foundry class, showed the possibility of speeding up the process by 30–33% compared to the base bath under the conditions of optimal argon purging flow rate.

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