Надійшла до редакції 27.11.2012 Рецензент д-р техн. наук, проф. О.М. Смірнов

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ФІЗИЧНЕ МОДЕЛЮВАННЯ ДВОСТАДІЙНОГО ВІДСІКАННЯ ШЛАКУ В КИСНЕВОМУ КОНВЕРТОРІ

Розроблена та виготовлена фізична модель кисневого конвертера , яка дозволяє моделювати процес випуску сталі та шлаку. Проведені дослідження по визначенню впливу в'язкості шлаку на його випередження потоку сталі під час нахилу конвертера. Підтверджено вплив міжфазного натягу поплавок – метал – шлак на роботу поплавка. Встановлена закономірність впливу співвідношення питомої маси поплавка до його робочої поверхні на якість відсічки.
Ключові слова: конвертер, льотка, фізичне моделювання, відсічний елемент.

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PHYSICAL SIMULATION OF TWO-PHASE SLAG CLOSING IN LD CONVERTER

A physical model of BOF is developed and produced. It can simulate the process of steel and slag outputting. Research is aimed at defining the influence of slag viscosity on its proactive steel flow during the converter tilt. The influence of interfacial tension 'float - metal – slag' on the floats work is discussed. The laws of the specific influence of the ratio of float mass to its surface on the quality of the cut-off process are defined.
Keywords: converter, hive, physical simulation, gate element.

UDK 669.187.2

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IMPROVING BATH GEOMETRY AS A WAY OF INCREASING EAF THERMAL EFFICIENCY

Numerical simulations of time depending problem for electric arc heating of molten steel bath, stirred by inert gas through bottom porous plugs has been made. For 120-ton AC EAF we showed the possibility of 12…16% reduction of the liquid bath heating time up to tapping temperature and 5…6% heat loss reduction due to the decrease of ratio between bath diameter and height from traditional 5,5 to 3,0.

Keywords: electric arc furnace, bath geometry, numerical simulations, thermal efficiency.

State of the problem

Improving electric arc furnaces (EAF) energy efficiency is one of the major problems of modern electrometallurgy. Traditional EAFs with bucket charging have thermal efficiency of 70 ... 75%. Thus, up to 25 ... 30% of the input energy is lost in the melting process. The main items of the losses are the heat radiated from the working space to water-cooled furnace elements, and the heat loss with off-gas. The heat cycle in intensive two-stage technology includes the period of melting and period of heating before tapping. The first period is the most power-consuming, but relatively energy-efficient, as it occurs at the time when energy sources are mainly screened by heating and melting charge. Second period is relatively energy-spending and takes place at the open radiating bath surrounded by water cooled elements of the working space, in which heat is lost.

Innovative technical and technological solutions, particularly Consteel, reduce energy loss by 25 ... 40% due to utilization of off-gas sensible heat for heating the charge continuously fed into the molten bath through a side tunnel by the pipeline. [1] However, in the Consteel EAF relative heat loss by cooling water is higher than in EAF with bucket charging because water-cooled elements are not screened by charge and are continually exposed to the radiation of the molten bath.

Historically, the ratio of the bath diameter to its depth D/h is 3.8 ... 6.2 [2], while in the BOF (the most high-performance steelmaking unit) it is close to 1. Thus, EAF bath is flat and shallow, and such configuration is for the following causes:

- providing high surface area of metal-slag contact for steel extraction refining in accordance with the classic technology of smelting;
- reducing the heat flow from the electric arc to a nearby “slag belt” zone, limiting the furnace refractory lining life in general;
- providing charge melting at minimum cost, in particular, loss of heat, which in cylindrical furnace housing is achieved with the ratio of the height of the space to its radius of 1:1. In the case of one-bucket charge of the furnace the ratio D/h, to the first approximation excluding spherical bottom of the bath, is equivalent to the ratio of liquid steel density (ρ_l) to the bulk density of the charge (ρ_b).

Formulation of the problem

Thus, practically established limits D/h correspond to ρ_b = 1.8 ... 1.2 ton/m^3. Such values of ρ_b were typical at the turn of the revolutionary changes in EAF technology and design solutions in 70-80s of the 20th century. The development of two-stage technology of steel production (melting of semi-product in EAF and subsequent refining of steel by means of secondary metallurgy), which includes the injection in a liquid metal of powder materials and gases, forced bath mixing, the widespread use of water-cooled components in the workspace, require some adjustment of basic geometric parameters of the liquid bath to improve the energy efficiency of the furnace. These circumstances are more related to technology with continuous loading of the charge in the EAF, in particular Consteel, for which the problem of ratio between housing and bath parameters is less actual, than the problem of high relative energy loss by open radiating surface of the melt.

The results of theoretical and experimental research

It is of interest on the basis of numerical simulation to make a preliminary assessment of the bath parameters D/h influence on the main technical and economic indicators of the furnace: the productivity and the specific heat loss for a given mass of tapped steel and flow rate of inert gas through the bottom plugs. The rate of liquid bath heating by electric arcs can serve as a criterion of productivity , which, in general, is a measure of intensity of the convective flow in the bath caused by pneumatic stirring, by pressure of arcs on the bath and by natural convection, determining the rate of charge melting.

The rate of heating and mixing of the liquid metal bath by electric arcs in AC EAF due to natural convection for the stationary problem is studied in [3], depending on the length of the arc, but without account of deformation of the melt surface by arcs pressure and inert gas bath agitation.

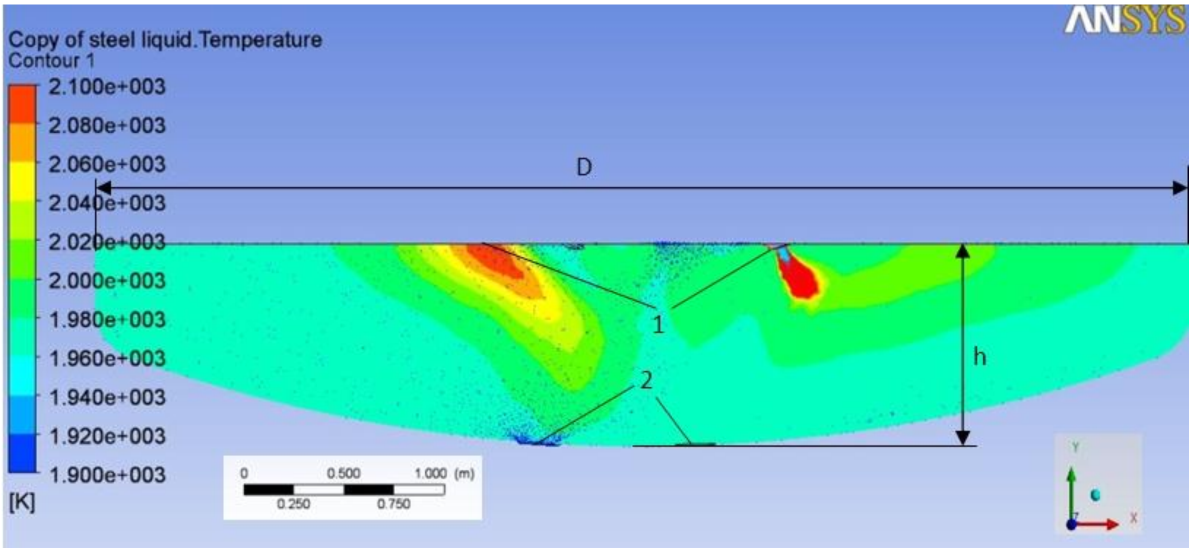
Numerical simulation for the non-stationary problem is fulfilled with the package ANSYS-v12 in order to assess the influence of bath geometry on the rate of liquid steel heating by electric arcs while stirring inert gas . The problem was solved for the following assumptions:

- bath of 120-ton AC EAF has a cylinder-spherical shape, bay EBT area, for simplicity is neglected;
- electrodes of 0,6 m diameter are installed with the pitch diameter of 1,25 m;
- two calculation options were considered: a) "small" bath: D_s = 5,50 m, h_s = 1,0 m, and b) "deep" bath: D_d = 4,35 m, h_d = 1,5 m;
- three bottom porous plugs provide constant uniformly distributed overall argon flow rate 0,4 kg/min. Plugs are fitted between the electrodes on the circle diameter equal to the electrodes pitch diameter;
- the surface of the bath is slag-free. It is known that the slag significantly changes the character of melt mixing, but for given comparative assessment its impact can be ignored;
- thermal properties of steel depend on the temperature;
- arcs create "wells" in the bath due to pressure caused by electrodynamics forces. The pressure force is directed at the angle 25 ... 300 to the vertical arc column [4].

The initial conditions for the domain "bath" are the following: the original (melting) temperature of liquid steel is 1475°C; surface temperature in the "well" under the arc is the boiling point of steel (2900°C); bath surface is free opening; on the sidewalls metal velocity is zero, convection heat flow into environment (through the refractory lining) is 6 kW/m^2 [2]; on the tubes surface mass flow rate of argon is given.

Mathematical description of the problem includes the equation of conservation of energy, momentum and mass. The standard k-ε turbulence model is used.

The simulation results in the form of a temperature field in the volume of metal in the vertical cross section are shown in Fig. 1.



1-«wells» under arcs, 2 – bottom porous plugs.

Figure 1 – Temperature field in the EAF liquid steel bath.

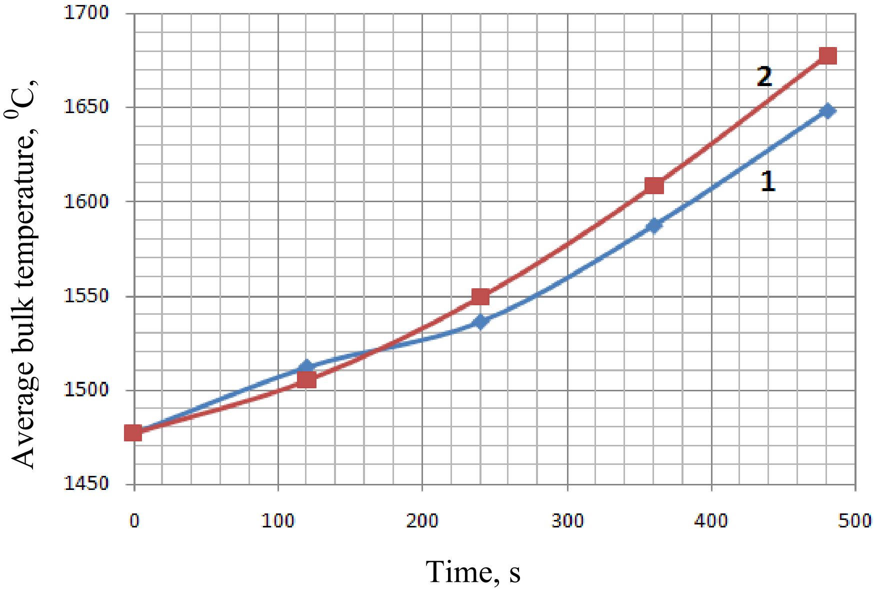
The obtained temperature field is a result of the impact on the bath of the arc columns pressure forces; pneumatic mixing by inert gas blown through porous plugs and natural convection.

Fig. 2 shows the time change of the average metal temperature value, obtained as a result of numerical experiments for the conditions listed above, with respect to the "shallow" and "deep" baths.

Behavior of the curves can be explained by the influence on the bath of natural convection from arc spots and of arc pressure force (from the top) and by the influence of forced convection caused by the movement of gas stirred metal (from below).

If natural convection provides a slow heating of a deep bath by the arcs, the mixing power, characterizing forced convection, is much more in a deep bath, other things being equal (metal mass, inert gas flow rate). Apparently, the last factor in the course of time becomes crucial.

Specific pneumatic mixing power (N_{mix}, W/ton) is defined as a work of isothermal expansion, done by a unit of gas volume per a time unit for a mass unit of liquid steel. At the same time, averaging the composition and temperature of the metal bulk (with a degree of 90% - for the conditions of practice) is inversely proportional to $(N_{mix})^{0,4}$ [5].



1 -"shallow" bath, 2 - "deep" bath.

Figure 2 – Average metal bulk temperature versus time.

Assuming that heating and homogenizing the bath have the same mechanism, and proceeding from the considered situation we can estimate the ratio of homogenization time in the "shallow" (h_s = 1,0 m) and "deep" (h_d = 1,5 m) baths (under atmospheric pressure in the furnace above the bath) as:

$$\left[\frac{\ln\left(1+\frac{h_d}{1,48}\right)}{\ln\left(1+\frac{h_S}{1,48}\right)}\right]^{0,4}=1,13 \qquad (1)$$

where 1,48 is a hydrostatic column of liquid steel, m.

The results (Fig. 2) indicate the possibility of reducing the time of heating the bath from 1500 to 1650°C by 12 ... 16% by increasing the depth of the bath from 1,0 to 1,5 m (D/h varies from 5,5 to 3,0).

Calculated on the basis of the method [5], the ratio of heating time of the "shallow" and "deep" baths (1) correlates well with the simulation results (Fig. 2).

In assessing the influence of bath geometry on heat loss with radiation through water-cooled furnace elements the following assumptions are made:

– liquid period of the heat is considered as the least energy-efficient;
– the radiation source is a bath and the lateral surface of the electrodes. Radiation from the arcs under foaming slag technology is fully absorbed by the bath;

– in calculating radiation of electrodes, they are represented as a cylinder with the diameter equal to the electrodes pitch diameter, height of this cylinder being equal to the height of the space above the bath;
– gas-oxygen burners in the liquid period of the heat are not used, so the irradiation of the torches is not taken into account;
– CO post-combustion factor is not considered, because the process is over outside the workspace, and due to gas emission line spectrum its contribution is insignificant and does not depend on bath geometry;
– the energy of exothermic reactions during the liquid period of the heat is taken into account by temperature of the bath;
– radiation energy is completely absorbed by the cooled surface of the bathroom working space, which is convenient for comparative assessment of different bath geometry options;
– diameter of the EAF working space is equal to the bath diameter. EBT area is not considered. The ratio of the radius of the workspace to its height is assumed to be 1 (from the condition of minimizing the surface and the heat loss through it).

Reducing the bath diameter results in the decrease of radiated energy to the EAF working space proportionally to the bath area. However, it increases the emission from the electrodes, the surface of which is close to the EAF casing. Analysis of geometry factors influence on the heat loss by radiation is made for the following values of the input parameters: the temperature of the liquid bath t_b=1620ºC, the average surface temperature of the electrodes t_e = 1200°C, the emissivity of the bath and the electrode respectively ε_b = 0,56, ε_e = 0,85, diameter of "shallow" and "deep" baths respectively D_s = 5,5 m, D_d = 4,35 m, electrodes pitch diameter D_p = 1,25 m.

Analysis is reduced to comparative assessment of the radiation power according to Kirchhoff's equation and leads to the factor (k_{loss}), representing the ratio of heat loss in the EAF water-cooled elements for cases of "shallow" and "deep" baths:

$$k_{loss} = \frac{D_S^2 \cdot \left[\dfrac{2D_P\varepsilon_e\left(t_e+273\right)^4}{D_S\varepsilon_b\left(t_b+273\right)^4} + 1 \right]}{D_d^2 \cdot \left[\dfrac{2D_P\varepsilon_e\left(t_e+273\right)^4 \cdot \left(D_S - D_P\right)}{D_d\varepsilon_b\left(t_b+273\right)^4 \cdot \left(D_d - D_P\right)} + 1 \right]} \qquad (2)$$

In the considered options of the EAF bath geometry, the transition from a "shallow" bath to a "deep" one, according to (2), allows reducing the heat loss with cooling water by 36%. Taking into account that given component of total energy losses constitutes about 15% in the EAF energy balance, we should expect the decrease of energy consumption for melting by 5 ... 6%.

Conclusion

The problem of increasing the EAF energy efficiency by improving bath geometric parameters, applied to two-stage technology of modern steelmaking, is considered. On the basis of numerical simulation of non-stationary problem of electrical arcs heating of a liquid steel bath, stirred by inert gas through the bottom porous plugs, we showed the possibility of accelerating the heating rate to the tapping temperature by 12 ... 16% and of reducing heat loss by 5 ... 6% due to the decrease the ratio of bath diameter to bath depth from 5,5 to 3,0 in 120-ton AC EAF. The results, in particular for heat loss, are expected to reduce specific energy consumption by 35 ... 40 kW·h/ton.

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Надійшла до редакції 02.07.2012 Рецензент д-р техн. наук, проф. О.А. Троянський

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ВДОСКОНАЛЕННЯ ГЕОМЕТРІЇ ВАННИ – ШЛЯХ ДО ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ДУГОВОЇ СТАЛЕПЛАВИЛЬНОЇ ПЕЧІ

Виконано чисельне моделювання нестаціонарної задачі електродугового нагріву сталеплавильної ванни, що перемішують інертним газом крізь донні пористі пробки. Для 120-т печі змінного струму показана можливість прискорення нагріву рідкої ванни до температури випуску на 12…16% та зменшення втрат тепла на 5…6% при зменшенні відношення діаметру ванни до її глибині з традиційного 5,5 до 3,0.
Ключові слова: дугова піч, геометрія ванни, чисельне моделювання, енергоефективність.

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СОВЕРШЕНСТВОВАНИЕ ГЕОМЕТРИИ ВАННЫ – ПУТЬ К ПОВЫШЕНИЮ ЭНЕРГОЭФФЕКТИВНОСТИ ДУГОВОЙ СТАЛЕПЛАВИЛЬНОЙ ПЕЧИ

Выполнено численное моделирование нестационарной задачи электродугового нагрева сталеплавильной ванны, перемешиваемой инертным газом через донные пористые пробки. Для 120-т печи переменного тока показана возможность ускорения нагрева жидкой ванны до температуры выпуска на 12…16% и снижения потерь тепла на 5…6% при уменьшении отношения диаметра ванны к её глубине с традиционного 5,5 до 3,0.
Ключевые слова: геометрия ванны, численное моделирование, энергоэффективность.

UDC 669.187.2

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SIMULATION OF ELECTRIC ARC FURNACE OFF-GAS REMOVAL SYSTEM IN ORDER TO INCREASE ITS THERMAL EFFICIENCY

On the basis of hydrodynamic equations a mathematical model of electric arc furnace exhaust flue gas removal is developed, which was validated by numerical calculations and physical experiments. Using the application package CosmosFloWorks in SolidWorks software, numerical simulations of advanced off-gas removal system of modern 120-ton electric arc furnace, aimed at improving the energy efficiency of steel production, have been made. The possibility of reducing specific energy consumption by 10 ... 13 kW·h per ton of steel by lowering heat loss with technological gas and dust emissions is shown.

Keywords: electric arc furnace, off-gas removal system, numerical simulations, thermal efficiency

State of the problem

Electric arc furnaces (EAF) melt about 40% of the world steel production. Modern steelmaking technology in the EAF is accompanied by off-gas emissions 100 ... 270 m^3/hr (under standard conditions) per ton of steel [1] with the dust content 15 ... 60 g/m^3 [2]. Off-gas composition is presented mainly by nitrogen, oxygen, carbon oxide and dioxide, water vapor. Melting dust contains mainly iron oxides, carbon particles and other burden metals oxides mixture. Specificity of the EAF off-gas removal process is that:

- due to a relatively small cross section area of the suction the elbow gas flow velocity under the negative pressure in the gas cleaning system is high, and that contributes to removal of charge materials from the furnace in form of oxidized dust and small particles;