The influence of uncontrolled disturbance actions on control of converter melting

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Abstract

The influence of uncontrolled disturbance actions on the output parameters of the converter melting was studied. Research shows that the solidified pig iron is present in the bath during 40 ... 50% of blowing, and scrap with low bulk mass melts at the beginning of blowing. It is calculated that mixer slag when adding to the converter also behaves as a coolant. All this leads to a decrease in the reaction zone temperature.

The numerical values of the influence of scrap contamination, the mixer slag ingress to the pig iron, limestone instead of lime and water from the cooling elements on the decarbonization, the bath temperature and the basicity of slag are given in the article. The results of obtained dependencies accounting on the control of converter melting are analyzed.

Key words: CONVERTER, PARAMETERS, IMPURITIES, SCRAP, SLAG FORMATION, MELTING, UNCONTROLLED DISTURBANCES, CHEMICAL COMPOSITION

Introduction

The nonstationary and mutually correlated noises and measurement errors, a significant drift of the operating parameters due to the presence of uncontrolled disturbances are inherent to the computer melting. For example, scrap impurities and mixer slag falling into the converter during the operations of loading and pouring not only distort the information about the mass of metal part of the charge, but also lead to disruption of the process, which worsens the control quality. The growth in mass of mixer slag by 1% increases rejected slag by 0.1% and the duration of blowing by 0.7 min [1]. By reducing the water falling into converter that cools the lance or converter gas cooler (CGC) by 10 l/min the pig iron expenditure is decreased by 0.2…0.5 kg/t of steel [2].

Metal scrap is characterized by the chemical composition, temperature and bulk mass. Bulk mass affects the process temperature course significantly changing the time of scrap melting. Investigations carried out show that when pouring pig iron, the melt is partially solidified as a result of reducing its temperature when contacting with scrap and lining. In the high-capacity converters solidified pig iron is present in the bath at a considerable interval of time (during 40…50% of blowing). At low bulk mass scrap is melted at the beginning of blowing, which reduces the temperature of the reaction zone, but at a high bulk mass melting is more uniform. Calculations show that in this case heat accumulated in the bath to 25% of blowing duration would be sufficient to melt all the scrap. Availability of unmelted scrap during 80% of blowing indicates a small value of the heat flow from the liquid bath to solid lumps. This can be explained by a low level of heat transfer processes in the bath due to its great heterogeneity and small contact of scrap surface area with the liquid melt.

It should also be noted that the overcooling of the bath when using scrap with low bulk density causes inhibition of reaction $Fe + CO_2 = FeO + CO$. As a result the proportion of carbon oxides to CO_2 is increased that promotes the growth of the thermal potential of melting. Using the scrap with low bulk density allows us to reduce pig iron consumption by 4.35 kg/t of steel [3].

The only way to control the bulk density of scrap is the amount of loaded chutes for melting. But such control is rough. Therefore, the most rational method of eliminating the influence of the disturbance actions is averaging the scrap on the scrap yard according to the chemical composition and the bulk density. Averaging is also required on the content of CO_2 in burned lime. To achieve the same quality of lime can be by unifying its production.

Statement of research objective

The objective of research is to improve the accuracy of converter melting control by determining and accounting the influence of initial disturbance actions on its course.

Scrap impurities

Scrap as impurities may contain sand, rust (scale) that influence decarburization modes, temperature and slag formation. Considering the proportion of sand $a_1$and rust a_2, % from scrap mass, the mass of these components can be expressed by formula

$$m_{1,2} = 0{,}01 a_{1,2} m_s \,, \tag{1}$$

where m_1, m_2 –mass of sand and rust in scrap respectively, t.

Since the scrap as a coolant due to impurities loads less, rising of the finished metal temperature in the converter, °*C*, when replacing scrap by sand and rust respectively equals

$$\Delta t_{1,2} = 9 a_{1,2} m_s / m \,, \tag{2}$$

where 9 – specific cooling effect of scrap, °*C*/1% from the mass of metal charge; $m = m_s + m_i$ – mass of metal charge, t.

In order to simplify the calculations we assume that the sand consists of 100% silicon oxide. Then, lowering of the metal temperature in the converter due to physical heating of sand can be defined as

$$\Delta t_3 = m_1 c_{sio_2} \bar{t}_m /(mc) \,, \tag{3}$$

where Δt_3 – cooling effect of sand, °C; c_{sio_2} – average specific heat of sand in the operating temperature range [4], J / (kg·K); $\bar{t}_m$ = 1620 – the average temperature of the metal on output from the converter, °*C*; *c* = 880 – average specific heat of bath in the range of converter operating temperature J / (kg·K).

Increasing of the metal temperature in the converter due to scorifying of sand Δt_4 , °*C*, amounted to

$$\Delta t_4 = 10^3 Q_1 m_1 /(mc), \tag{4}$$

where Q_1 = 2386 – specific thermal effect of sand scarifying reaction under standard conditions $SiO_2 + 2CaO = (CaO)_2 SiO_2 + Q_1$, kJ/(kg SiO_2) [4].

Reduction of the final slag basicity is due to sand scorifying of scrap is found according to the linear balance model for calculating the charge [5], converted into partial increment of the required quantity:

$$\partial B_1 = -75 m_{11} /(12.3 + 2.14 Si_i m_i), \tag{5}$$

where ∂B_1 –partial increment of the final slag basicity; m_{11}–is found according to the stoichiometric calculation formula

$$m_{11} = 2 \cdot 56 m_1/(60\ 0.862), \qquad (6)$$

where 56 and 60 –molecular weights of calcium oxide and sand, respectively; 0.862 –mass fraction of *CaO* in the lime [6].

Physical cooling effect of lime Δt_5 , °*C*, was

$$\Delta t_5 = m_{1_1} c_{\mathrm{CaO}} \bar{t}_{\mathrm{m}}/(mc)\,, \qquad (7)$$

where c_{CaO} – average specific heat of lime in the range of operating temperatures [7], J / (kg·K).

The total effect of temperature influence on the metal bath of sand falling with scrap $\Delta t_{\sum 1}$, °*C*

$$\Delta t_{\sum 1} = \Delta t_1 - \Delta t_3 + \Delta t_4 - \Delta t_5. \qquad (8)$$

Signs in front of the formula components (8) correspond to «+» – exothermic reaction, «–» – endothermic reaction.

The specific value of sand influence on the final blowing parameters, calculated at a_1 = 1 %, a_2 = 1 %, Si_i = 0.8 % and m_s/m = 0.24 are given in Table. 2.

Calculated by the same methodology total thermal effect of influence on the metal bath of scrap rust is present in the following form

$$\Delta t_{\sum 2} = \Delta t_2 - \Delta t_6 - \Delta t_7 + \Delta t_8, \qquad (9)$$

where $\Delta t_6, \Delta t_7, \Delta t_8$ - physical cooling effect of scrap rust, metal temperature decrease due to the decomposition of scrap rust, temperature increase due to the additional oxidation of carbon, °*C*, respectively.

Mixer slag

Mixer slag of average chemical composition, %

Fe_2O_3... 1.83 CaO... 17.15 Al_2O_3... 6.84
FeO... 6.02 MgO... 4.72 Cr_2O_3... 0.17
SiO_2... 47.50 MnO... 7.00 P_2O_5... 0.11

relates to acid slags with basicity in the liquid state, which content is 0.36.

The activity of silicon oxide in the slag is small even at its high proportions and decreases at an excess *CaO*, since the strong, high-melting compound in the form of calcium orthosilicate $2CaO \cdot SiO_2$ is formed with melting temperature of 2130 °*C*. On the slag melting temperature t_{mel}, °*C*, the greatest influence has the change of mass fraction of SiO_2, which value in the range of 30... 35 % is a boundary condition for the maximum of basic slag and minimum of acid slag [4]

$$t_{\mathrm{mel}} = 1680 - 28 SiO_2 + 0.43 (SiO_2)^2. \qquad (10)$$

Differentiating function (10) according to SiO_2 and equating the derivative to zero, we find a minimum mass fraction of SiO_2 therein according to the melting temperature of the slag. It is equal to 32.5 % (Fig. 1, dashed line). As can be seen from the figure the melting temperature of both acid and basic slag increases during melting. This is mainly due to the change in conditions of dissolution in acid slag of SiO_2, and in basic slag of *CaO*.

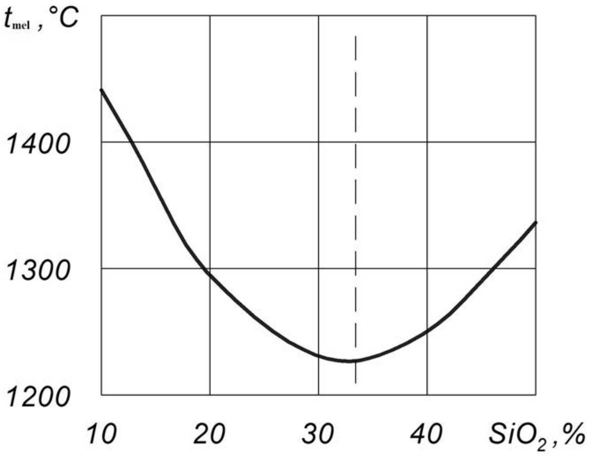

Figure 1. The dependence of the slag melting temperature t_{mel} from mass fraction of silica SiO_2 therein. Dashed line is the conventional boundary of acid (the right area) and basic slag

The melting temperature of mixer slag is 1317 °*C*, the average temperature of poured pig iron is 1300 °*C*, therefore, consistency of mixer slag in the convert bath at the beginning of blowing is “dry” with a partial or complete loss of fluidity.

For one-slag oxygen-converter process taking into account the most common limits of changing of the finite slag parameters the values of the campaign life may be taken as average, %:

Fe_2O_3...5.0 CaO...54.0 Al_2O_3...1.50
FeO...8.0 MgO...9.1 S...0.10
SiO_2...16.5 MnO...4.0 P_2O_5...0.80

According to the data of Table 1, it is calculated that 1% of the mixer slag

(a_5 = 1 %) in conversion according to the average mass of the final slag is 5% at the expense of mass of slag-forming lime this figure is increased by 2 times.

$$a_6 = 100 a_3 m_{\mathrm{i}}/(m \overline{m}_{\mathrm{sl}})\,. \qquad (11)$$

Calculations on the balance model show that the mixer slag entering the converter behaves as cooler. Cold start of blowing is aggravated by the low values of pig iron temperature, mass fraction of manganese and silicon therein, high scrap expenditure with low bulk density (0.7 t/m^3) etc. There is a significant accumulation of iron oxides in slag during the first blowing period, since the mass transfer is slowed down in the bath. Further these factors after bath heating-up lead to an intense uneven oxidation of carbon and rapid dissolution of lime by actively assimilating influence of the iron oxides. All this may lead to emissions in the middle of blowing and metal losses, sometimes reaching 2…5% from the pig iron mass [8].

Table 1. Typical parameters of final slag 1)

Mass fraction of silicon oxide, %		Slag mass kg/100 kg of metal charge		Basicity	
SiO_2	SiO_2	m_{sl}	$\overline{m}_{sl}$	B	B
14...19	16.5	13...17	15	3.0...3.5	3.25

1) The bar over the parameter indicates its average value.

In any slag crucial importance has interaction of acidic and basic oxides. It can be assumed that in the slag CaO is always in compounds, and other basic oxides combine when a shortage of CaO is observed. Let us consider in the system $(CaO + MgO) - (SiO_2 + Al_2O_3) - (\sum FeO + MnO)$ the possible ways of slag formation. The ultimate objective of the slag formation process is to saturate slags with lime that provides deep removal of harmful impurities from the converter bath. Initially, the accumulation of slag phase from the mixer slag components occurs due to low melting components, then the main role in slag mass increasing proceeds to the process of lime dissolution.

Evaluation of the slag formation kinetics of slag mixing components is made according to mass rate of fluxing lime dissolution $\dot m_1$, kg/s, [7]:

$$\dot m_1 = 0.305(-39.1 + CaO + 1.35MgO - 1.09SiO_2 + \\ + 2.75\sum FeO + 1.9MnO)exp(-2550/\overline{T})\ \overline{v}_C^{0,7} m_{12}^{0,5}, \tag{12}$$

where CaO, MgO, SiO_2, MnO –mass fraction of oxides in the final slag, %; $\sum FeO$ –the total mass proportion of iron oxides in the final slag recalculated to an equivalent proportion of iron monoxide, %; $\overline{T}$ –the average temperature of the bath during the initial blowing period, K; $\overline{v}_C$ – average velocity of the bath decarburization in the same period,%/min; m_{12} –forecasted lime part on the melt that went to the slagging of mixer slag components, kg.

Calculation according to formula (12) the value m_1 = 33.6 kg/s was found when a_5 = 1 %, m_i = 125 t, $\overline{B}$ = 3.25, $\overline{T}$ = 1400 + 273 K, $\overline{v}_C$ = 0.15 %/min and m_{12} = 2000 kg.

The final chemical composition of slag can be obtained traditionally by “lime” (ferriferous) or “ferrite” way. “Lime” way is used for soft-burnt lime, “ferrite” is associated with an increased oxidation of slag and is used for solid- burnt flux. When “lime” way the slag composition passes through the high-melting area $2CaO \cdot SiO_2$ (concavity of the curve in Fig. 2 in direction opposite to the top corner of $\sum FeO + MnO$. In order to prevent “rolling-up” of slag and subsequent emissions, it is necessary to increase the expenditure of fluorspar to 4…5 kg/t of steel or the height of the lance above the bath.

When “ferrite” way of slag formation the trajectory bends around the diagram ledge $2CaO \cdot SiO_2$, passing towards vertex of the angle CaO through the area of low-melting compounds (Fig. 2, curve 2). Most low-melting compounds and a mixture of phases are obtained in the system $CaO - \sum FeO$. The melting temperature of two-component systems $CaO - \sum FeO$ and $CaO - Fe_2O_3$ are 1140 and 1230 ^0C respectively [8]. Low melting compounds also form manganese oxides. Slagging in this case is optimal. It provides a maximum from the start of blowing lime dissolution rate (not less than 40 kg/s) to obtain a homogeneous highly basic slag.

In case of mixer slag penetration instead of pig iron the mass of letter decreases, which leads, on the one hand, to underheating of bath and increase of final slag basicity, and on the other – to the decrease in basicity, since one part of added lime is spent on slagging SiO_2 of mixer slag, and carbon over burning, which is oxidized stoichiometrically taking into account constant volume of oxygen blowing. In this case the excess enthalpy of the melt from the chemical reaction heat of carbon over burning does not occur.

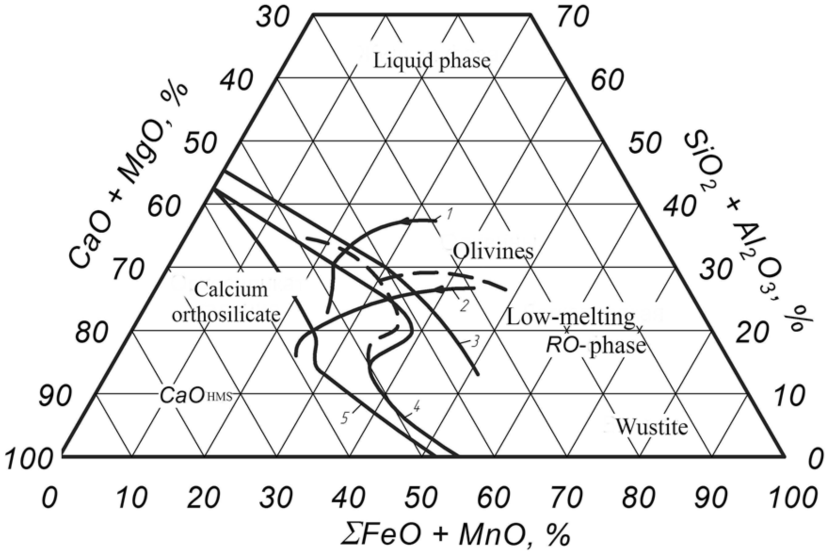

Figure 2. A trajectory of slag formation within quasiternary diagram in the period of bath blowing of 130 tons oxygen converter using scrap as a coolant: 1, 2 –1, 2 – isospeeds of lime dissolution in normal and optimal process respectively; 3, 4 - melting isotherms at 1400 and 1600 °C respectively; 5 – of slag saturation curve $2CaO \cdot SiO_2$, $3CaO \cdot SiO_2$ and CaO at 1650 °C; – boundary of mineralogical components

Influence of mixer slag and pig iron penetration in the converter on the melting results is given in Table. 2. The effect of underburned lime and moisture ingress from the lance or cooler of converter gases is also shown.

The results obtained are used in the algorithms of static and dynamic closed cycle control of output parameters. The number of melts produced from the first turndown increased by 7%.

Table 2. Impact of uncontrolled bath disturbances on the final blowing parameters

Disturbance	The impact on the final parameters		
	Mass proportion of carbon in the metal,%	Metal temperature, °C	Slag basicity
Replacement of 1% of the scrap mass: by sand rust (scale)	– – 0.05	– 0.9 – 4.18	– 0.286 –
Ingress of 1% of the scale from scrap mass	– 0.05	– 9.7	–
Replacement of 1% of the pig iron mass by mixer slag	– 0.033	– 16.04	– 0.065
Ingress of 1% of mixer slag from the pig iron mass	– 0.032	– 14.0	–
Replacement of 1% of the lime mass by limestone	– 0.0011	– 1.37	– 0.015
Ingress of 0.1 % moisture from the pig iron mass from the lance of BOF gas cooling	– 0.0512 – 0.0358	– 26.2 – 18.3	– –

Conclusion

Results of evaluation of the uncontrolled disturbances impact on the course of converter melting showed their considerable value as on the process of baths decarbonization, its temperature, and slag formation. Take into account this influence is possible by the introduction of closed-cycle on the results of melts or dynamic parameters control. A significant decrease in the impact of uncontrolled disturbances can be achieved by careful preparation of the raw materials.

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