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Metal Oxidation Control at the Stage of Refining Steel Smelting in Electric Arc Furnaces

Sivtsov A.V.[1], Sheshukov O.Yu.[1,2], Tsymbalist M.M.[1], Nekrasov I.V.[1,2], and Egiazaryan D.K.[1,2]

[1]Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences, 101, Amundsen street, Ekaterinburg, Russia
[2]Ural Federal University named after the first President of Russia B. N. Yeltsin, Ekaterinburg, Russia

Abstract

The mathematical processing results of a number of EAF-135 melts electrical parameters are presented. The influence of the foamy slag formation, molten metal carburization and the harmful impurities oxidation on the change in electrical parameters is analyzed. The methodology for determining the metal oxidation from the electrical melt parameters is characterized. In the presented form, the technique is cumbersome for the rapid assessment of the oxidation process intensity and requires refinement.

Keywords: Metal oxidation, electric parameters, electric arc furnace

Corresponding Author:
Sivtsov A.V.
aws2004@mail.ru

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The slag regime and the oxidation stage of the process play a special role in the technology of electric smelting of steel intermediate, since technical and economic indicators (TEI) of both the smelting itself and subsequent metal processing in the ladle-furnace unit (LFU) depend on their implementation. The main tasks of this period include: the formation of slag melt, carburization of the metal with the aim of organizing intensive mixing of the liquid bath and oxidizing the metal with the removal of carbon and converting the impurities contained in it to slag [1, 2].

The most important parameters for controlling the intensity and completeness of the processes occurring at this stage are the basicity of the slag (in practice, V_{sl} = CaO/SiO_2 is mainly used) and metal oxidation ($[O]_{Me}$).

Oxidation of a metal is called the activity of oxygen dissolved in it. There are probes for determining the oxidation of a metal during the process. However, their high cost, disposability and unstable response prevent their frequent use [3, 4].

In our studies, aimed at developing a method for continuous monitoring of metal oxidation, we used an automated system for monitoring electrical parameters that we developed and a method for determining the constant component of an electric arc

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[5, 6]. To assess the influence of the parameters and technological characteristics of the process on the constant component of the electric arc, studies of the electrical regime of electric arc furnace-135 (EAF-135) were carried out.

This article presents the results of measurements of 24 meltings carried out during 24 hours. Measurements and recording of electrical parameters were carried out every 10 seconds. Data on the time and mass of loads of scrap, carbon and slag-forming materials, durations of various stages of smelting, the consumption of oxygen and natural gas, as well as the chemical composition of the metal and slag, and data on measurements of temperature and oxidation of the metal were obtained from the melting passports.

Metal refining with oxygen begins with the introduction of slag-forming and carbon materials immediately after the scrap melting. At this time, three processes occur almost simultaneously: the foamy slag formation, molten metal carburization for its subsequent mixing during oxidation (“bubbling”) and the oxidation of harmful impurities contained in the melt by blowing it with oxygen. All these processes affect the constant component of the arc voltage (CCAV). Figure 1 shows a fragment of the characteristic of the change in the CCAV corresponding to the melt oxidation period. It also presents results of determining the oxidation of the melt using probes (characteristic [O]).

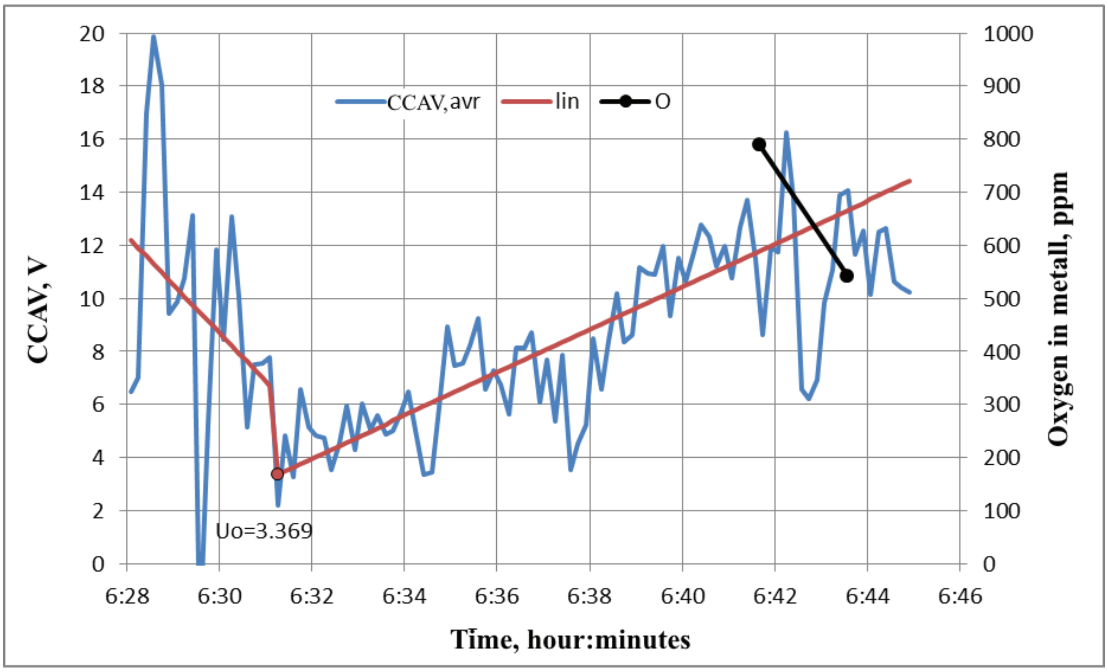

Figure 1: Changes in the CCAV during oxidative melting period. Designations; lin- linear approximation of the ascending and descending sections of the characteristic; O - metal oxidation

The characteristic has two sections: descending and ascending. The descending section corresponds to the processes of slag formation and melt carburization. The general tendency towards a decrease in the CCAV is due to the linear process of carbon accumulation in the molten metal and the process of mutual dissolution of SiO_2 and CaO, which has an exponential character.

The ascending section corresponds to the process of dissolution of oxygen in the melt, i.e. the oxidative process itself. However, the application of this characteristic directly to control the oxidation of a metal is not entirely justified, since it also includes a change in the CCAV corresponding to the end of the process of oxidation of carbon dissolved in the melt. Therefore, correction of this characteristic is required due to separation of components from it that correspond to the accompanying processes.

Since the oxygen introduction to the furnace occurs at a constant speed q_{O2}= 9000 m^3/h, it is possible to use the oxygen flow rate at a given point in time instead of time as an argument to this dependence τ

$$G_{O_2}(\tau) = \int_0^{\tau} q_{O_2} dt \tag{1}$$

Figure 2 shows the CCAV dependence ($U_0{}^{sm}$) on the oxygen flow smoothed out using a moving average filter:

$$U_0^{sm} = \frac{1}{2N+1} \sum_{i=-N}^{N} U_{0i}, \tag{2}$$

where, U_{0i} – CCAV, N– half-width of the smoothing interval.

The parameters and characteristics determining methodology for all three processes that affect the CCAV changes consists of several stages. Note that the characteristics of melt carburization and stable slag foam formation are transient and can be described by a falling exponential time dependence of the type U(t)=A*exp(-α/τ). In this case, the parameter τ has the meaning of a time constant for transient. That is, the CCAV change over time, due to the oxidation of the melt, can be represented as

$$U_0^{sm}(t) = U_S(t) + U_C(t) + kG_{O_2}(t) + b \tag{3}$$

where, U_s(t) and U_c(t) – transients of slag stabilization and melt decarburization, G_{O2}(t) – oxidation process.

To increase the accuracy of monitoring the metal oxidation, it is necessary to isolate a component that directly depends on the oxygen introduction to the furnace from the general characteristic U_0(t). It is accepted in control theory that the transition process is completed after a time period three times greater than its time constant. Thus, if we choose the interval in the last quarter of the temporary implementation, it can be argued that by this moment the transition process caused by the slag stabilization process has already been completed.

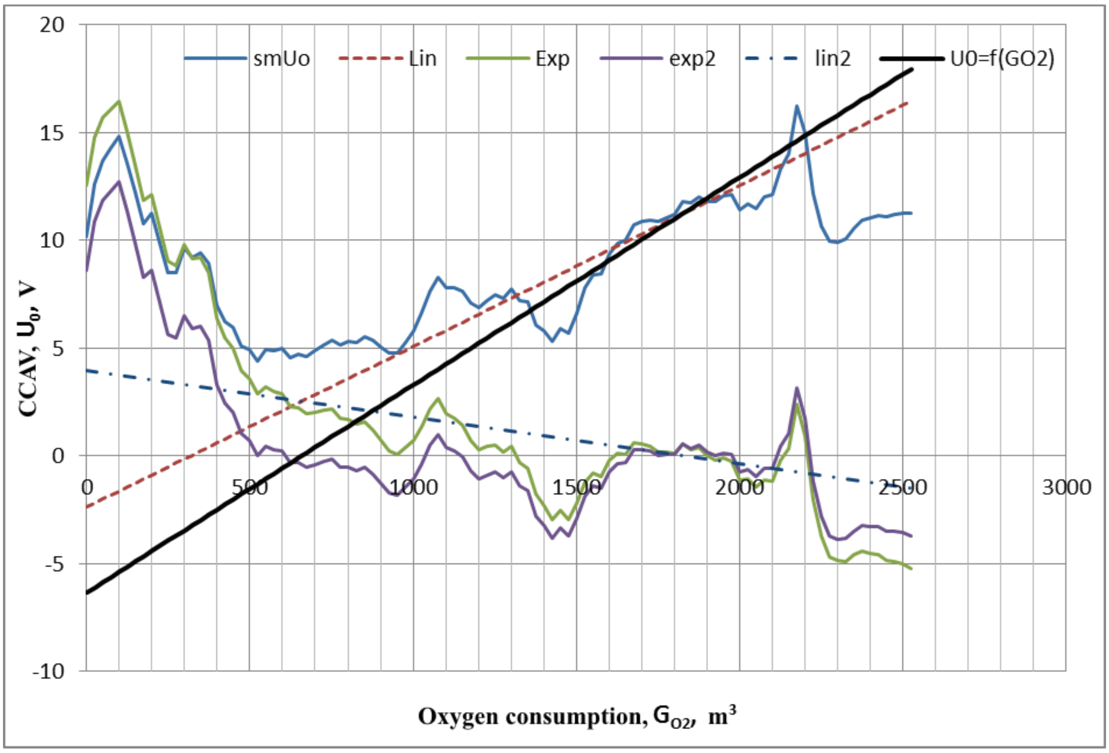

Figure 2: Determination of the oxidation metal characteristics. Designations: smU$_0$ – smoothed CCAV; Lin - ascending section linear approximation; Exp - difference characteristic U$_E$ (4); exp2 – difference characteristic U$_S$ (5); lin2 - linear approximation of U$_E$ descending section, U$_0$=f(G$_{O2}$) – corrected characteristic of the metal oxidation.

Assuming that the metal oxidation process is linear, we will approximate the initial characteristic in this section by a linear dependence$U_0 = k_1 G_{O_2} + b_1$, subtract it from the initial implementation (i.e., over the entire time interval), and obtain

$$U_E = U_0^{sm} - k_1 G_{O_2} - b_1 = U_S + U_C \tag{4}$$

Then the U$_E$ characteristic is a reflection of the total process of slag stabilization and metal carburization. In the last quarter of the time interval, the slag stabilization process has already been completed, and the damped part of the exponent corresponding to the carburization process can be represented as a decreasing linear function. Then, having carried out a linear approximation of its last quarter $k_2 G_{O_2} + b_2$ and subtracting it from the curve U$_E$, we obtain an exponential function that describes the process of stabilization of slag:

$$U_S = U_E - k_2 G_{O_2} - b2 \tag{5}$$

That is, we isolated from the general dependence the characteristics corresponding to the processes of slag stabilization and carburization of the melt. Further, it is easy to obtain, by forming the difference characteristic of two linear approximations, the adjusted CCAV dependence on the oxygen flow:

$$\tilde{U}_0(t) = k_1 G_{O_2} + b_1 - k_2 G_{O_2} - b_2 = \left(k_1 - k_2\right) G_{O_2} + b_1 - b_2 = k_0 G_{O_2}(t) + b_0 \qquad (6)$$

Next, we need to go from the CCAV values to the metal oxidation values. We can find their dependence according to the regression equation (7) obtained by studying the technological and electrical parameters of ASF-135 based on 260 smelt results. A graph of this dependence with a change in basicity in the range from 1.8 to 2.0 is shown in Figure 3.

$$[O]_{Me} = KU_0 + C \qquad (7)$$

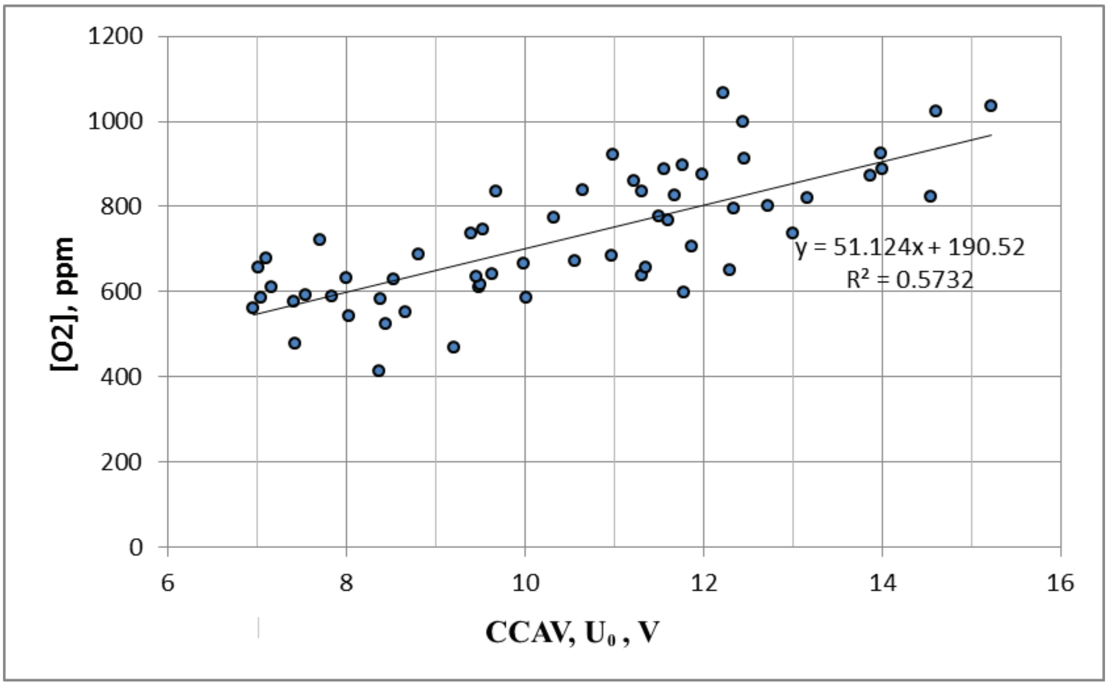

Figure 3: Connection of metal oxidation with CCAV

Table 1 presents parameters of the regression equation, obtained for various intervals of slag basicity variation. It is easy to see that the proportionality coefficients K practically do not differ, small differences are observed for the free term C.

Table 1: Regression equation coefficients $[O]_{Me} = KU_0 + C$

Basicity	K	C
1,6-1,8	51,57	216,3
1,8-2,0	51,12	190,5
2,0-2,2	51,11	211,4
2,2-2,4	51,11	199,7
2,4-2,6	51,91	235,7

The presented methodology, due to the complexity of the procedure and the “blurriness” of the criterion for selecting sections for linear approximation, significantly complicates its software implementation and requires significant computational costs. Therefore, for practical purposes, one should consider the possibility of determining oxidation only by the equation for the final section of the initial characteristic.

To use the initial characteristic of the PS of the arc voltage as a criterion for changing the metal oxidation, additional information is required on the parameters whose values are determined only by the results of melting; therefore, this technique is suitable only for an approximate estimate of the intensity of the oxidation process. For the operational control of this parameter, mathematical processing of the initial characteristic by the above method is necessary, and additional studies of the influence of the main technological factors on it are required. In particular, it is necessary to monitor and record all changes made to the implementation of the oxygen blast regime, and timely registration of all changes in the charge mode of the charge materials. It should also be noted that the results of the technique are suitable only for the specific processes and units on which it was implemented, which, however, is not a critical problem in the modern development of computer technology and methods for automated control of process parameters.

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