STEEL DEOXIDATION AND ALLOYING CONTROL MODEL IN THE CONVERTER PLANT

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Introduction

Significant resources are spent for operations of steel deoxidation and alloying that, first of all, is related to the need of adding large amounts of scarce and expensive additives to it, especially at steel smelting in large-capacity aggregates. Steel grades standard guides provide for wide variations of deoxidizing elements which amount to, %: Mn 0.3 – 0.4; Si 0.2 – 0.3; Al, Cr, Ni, Nb, etc. - twice [1]. It's relevant to use such additives economy reserve as production of steel containing alloying elements on the lower limit of their concentration which is permissible by grade composition. But this is possible only by providing guaranteed stability of assimilation of alloying elements and homogeneity of their even distribution in steel.

The widespread application of technologies based on adding alloying metals in a solid state into steel leads to significant costs for waste, uneven distribution of steel volume and the need for overheating. It adversely affects the stability of the metal properties [2]. Technologies based on the usage of alloys in a liquid state substantially reduce waste and increase homogeneity of steel. But even such advance technologies as MAI process (Japan) do not provide a high degree of homogeneity and assimilation of alloying elements by steel. Moreover, the effectiveness of such technological processes is reduced when using traditional rather than specialized aggregates for transforming alloy additives into liquid. It's connected with exiguous and quite often substantial expenses on waste of alloying elements while melting and holding-up of liquid alloys in such aggregates, as well as the complexity of regulating the feed of alloy in the required zone of steel volume [3].

The interpretation of the concept of waste while introducing deoxidants into steel is ambiguous. On the one hand, binding of oxygen dissolved in steel is the aim of dioxidizing and consumption of additive elements to achieve this goal cannot be considered as their loss. On the other hand, for example, consumption of deoxidizers for the reaction with atmospheric oxygen and slag is irrational. Losses of elements that have a high sensitivity to O_2 (Ca, Al, Ti, etc.) often exceed 50% [4] and even 96% [5].

Target setting.

The aim of this work was to create a control model for the process of deoxidation and alloying of steel which provides production of steel containing deoxidizing and alloying elements near the lower limit set by the steel grade.

The results of research.

Researches were conducted in the converter plant with 160-ton converters. Deoxidation of oxygen converter steel was conducted by deep technique in a ladle during metal tapping. Deoxidants are not usually introduced into the converter to avoid large waste. In smelting of dead-melted steel deoxidants are introduced into the ladle on the metal stream in the following order: firstly, ferromanganese or silicomanganese followed by ferrosilicon and aluminum in the last turn. Introduction of deoxidants starts when the liquid metal ladle is filled by about 1/4 ... 1/3, and ends when it filled the ladle by 2/3 that helps to avoid getting deoxidants into the slag and their higher waste [1].

The weight of ferroalloys ($m_{фс}$, ton,) is calculated by the formula:

$$m_{фс} = \frac{\gamma(m_б + m_ч)(R_с - R_м)}{(1 - b_R)R_{фс}}, \qquad (1)$$

where γ, b_R – is a coefficient of metal waste during blowing (taken as equal to 0.9) and the deoxidant; $m_б$, $m_ч$ - weight of scrap and iron, ton; $R_с$, $R_м$, $R_{фс}$ – a given mass fraction of the deoxidant element in steel, actual one in metal before tapping into the casting ladle and in ferroalloy, respectively, %.

Deoxidant waste depends on the type of ingot, metal temperature, mass fraction of carbon and the deoxidant element in it, and varies broadly: during deoxidation of dead-melted steel - waste of Mn is 0.1 ... 0.25, Si - 0.15 ... 0.25; during deoxidation of rimmed steel waste of Mn is 0.2 ... 0.35. Consumption of aluminum is 0.15 ... 1.20 kg per ton of steel, and it increases with decreasing carbon content.

Coefficient of deoxidant waste is determined by the formula [6]:

$$b_R = \alpha_0 + \alpha_1 C_М^{-1} + \alpha_2 t_М - \alpha_3 R_М + \Delta\alpha \qquad (2)$$

where $\alpha_0...\alpha_3$ - the coefficients with values dependent on the type of deoxidant material; C_M - a carbon content in metal at the end of blowing, %; t_M - metal temperature at the end of blowing, C; $\Delta\alpha$ - correction determined by the results of previous meltings.

Potential cooling of the liquid steel by a large quantity of the alloying materials allows obtaining with the use of this technique of only a low-alloy steel with a total content of alloying elements not exceeding 2...3%.

There are no problems with alloying of those elements which have sensitivity to oxygen less than that of iron (nickel, copper, molybdenum). These elements could be introduced into the converter for the reason they do not oxidize in it.

The basis of the mathematical description of metal deoxidation technique is a control following “pattern” meltings [7]. Having the selection of control trajectories of the successful meltings ($\vec{U}_1[\tau],\dots,\vec{U}_n[\tau]$), we can talk about marking out in the real trajectories $\vec{U}_i[\tau]$ of two components: the program part $\vec{U}_{i\text{пр}}[\tau]$ and an additional control $\Delta\vec{U}_i[\tau]$, that is associated with both inaccurate determination of the initial state and with the action of hindrance. Control strategy cannot be reduced to a purely deterministic, and consists of deterministic (program selection) and stochastic (finding of additional control effects) parts.

We represent the control trajectory $\vec{U}_i[\tau]$ for each “pattern” melting operation, i = 1,…, n, in the form of a piecewise continuous curve in a multidimensional Euclidean space using a single step functions $1(\tau - \tau_i)$. Control effects $U_{ij}[\tau]$ that are implemented in the form of constant settings (deoxidants introduction mode) alternating in time can be expressed through a unit step function directly:

$$U_i[\tau] = \sum_{k=1}^{n_j} a_{kj}^i 1(\tau - \tau_i) \tag{3}$$

where a_{kj}^i - setting value for $\tau \in [\tau_i, \tau_i + 1]$; τ_i - moments of setting changes.

Two control trajectories $\vec{U}_i[\tau]$ and $\vec{U}_j[\tau]$ for the i^{th} and j^{th} sample melts are compared with each other by means of measure with a vector weight function.

$$\vec{H}(\vec{y}[\tau_0], \bar{x}, \tau) = [h_1(\vec{y}[\tau_0], \bar{x}, \tau), ..., h_p(\vec{y}[\tau_0], \bar{x}, \tau)],$$

$$d(\vec{U}_i[\tau], \vec{U}_j[\tau]) = \int_0^\tau \sqrt{\sum_{\nu=1}^{p} \{h_\nu(\vec{y}_i[\tau_0], \vec{x}_i, \tau)\vec{U}_{i\nu}[\tau] - h_\nu(\vec{y}_j[\tau_0], \vec{x}_j, \tau)\vec{U}_{j\nu}[\tau]\}} d\tau / T \tag{4}$$

where τ - the time counted from the start of metal tapping; $T = \max\{(\tau_{ki} - \tau_{01}), (\tau_{kj} - \tau_{01})\}$.

This distance $d(\vec{U}_i[\tau], \vec{U}_j[\tau])$ between the control trajectories for the i^{th} and j^{th} melts was used to divide control trajectories into classes S_1, S_2,…, S_k in such a way that each class S_i to be consistent with control trajectories $S_i \sim \{U_{i1}[\tau],\dots, U_{ik}[\tau]\}$, which are an implementation of a control program $\vec{U}_{i\,\text{опт}}[\tau]$ with different additional control effects $\Delta\vec{U}_i[\tau]$. This condition can be satisfied by selecting a weigh function that way the distance between the actual trajectories of the control to be less than the distance $d(\vec{U}_i[\tau], \vec{U}_\nu[\tau])$ for trajectories implementing various programs.

Dioxidizers are calculated by the formula (1) in two forms: calculation of the broad-brush and accurate dose. Here b_R is calculated by the formula:

$$b_R = b_R^0 + \alpha_1(1/C_M) + \alpha_2(t_M - t_M^0) + \alpha_3(R_M - R_M^0), \tag{5}$$

where index “^{0}” – is a value of “pattern” melting.

In case of absence of “pattern” melting (deoxidation) for any element, its waste coefficient is taken from the scale of average values, and the finite value - from the steel grades table.

The calculation is performed separately for the two concentrations of Mn in steel - minimum and average for smelted steel grade.

Parameters for the formation of an array of “pattern” meltings (deoxidation) are presented in Table 1.

Table 1. The parameters for the formation of “pattern” melting (deoxidation)

Name of parameter	Notation	Value	Tasted ranges	Quantity
Carbon content at turndown, %	$C_п$	0,05-0,25	<0,07; 0,07-0,10; 0,11-0,15; >0,15	4
Manganese content at turndown, %	$Mn_п$	0,08-0,30	<0,10; 0,10-0,20; >0,20	3
Steel temperature at turndown, ^{0}C	$t_п$	1560-1650	<1580; 1580-1610; >1610	3

Data in Table 1 are separately applied to such groups of steel:

- rimmed steel;
- semikilled steel;
- killed steel;
- low-alloyed steel;
- alloyed steel containing no chromium, nickel, copper, niobium, vanadium, nitrogen, molybdenum, titanium, boron, calcium, rare-earth metals;
- steel containing chromium;
- steel containing nickel;
- teel containing copper;
- steel containing titanium;
- steel containing niobium;
- steel containing vanadium;
- steel containing nitrogen;
- steel containing molybdenum;
- steel containing boron;
- steel containing calcium;
- steel containing rare-earth metals.

The deoxidants calculation program that implements this model is started by the master of production from the workstation of the platform or distributor machinist from converter's workstation from the main menu. To enter the appropriate grade of steel video footage should be used. If steel grade is not entered by the master before blowing, the program uses the steel grade entered by a distributor machinist for calculating the parameters of converter's blowing. Fragment of the program algorithm is shown in Figure 1.

In both cases, a video frame of the ferroalloys calculation is given in the workstation monitor of the platform (Fig. 2).

Broad-brush calculation of coarse deoxidants doze.

To make a broad-brush calculation of deoxidants on a video frame of deoxidants calculation the window "broad-brush" is activated by the master of production (when entering a grade of steel it is activated automatically). This changes the colour of the window from gray to red. The calculation is made by the formula (1) in which the content of the element in the metal at turndown is considered equal to the value of this element in the selected "pattern" melting after blowing. Assimilation coefficient is calculated by the formula (5), in which C_M and t_M are the values of the specified parameters after blowing.

Calculation results are given at the video frame (Fig. 2) "Ferroalloys calculation" in the corresponding windows for materials selected for deoxidation. The windows are also highlighted in red. The type of ferroalloy that is located in the hopper is chosen for deoxidation. If several types of ferroalloys from those that are in hoppers can be chosen for deoxidation, the type that was used in the "pattern" melting is chosen. Types of materials that do not come through the hoppers are chosen by "pattern" melting. The master has the ability to adjust the types of ferroalloys by activating their windows and putting out the windows of ferroalloys which are not used. To perform a re-calculation according to the adjusted settings it's necessary to click "Yes" in the "recalculate ferroalloys" window. The recalculation is performed by the formula (1) for other types of ferroalloys. To enter the calculation results in the "recalculate ferroalloys" window, press "No". Thus, windows with selected materials change their backlight colour to green.

At the same time the video frame "Dozing of ferroalloys" (Fig. 3) is formed to which the calculated values of the ferroalloys weight with distribution by feeds are transferred (red highlight). After adjusting of the ferroalloys type by the master the highlight of ferroalloys weight with distribution by feeds is changed to green.

Information about the weight of ferroboron, copper and nickel is transferred for their uploading into the converter together with scrap.

The calculation of the exact portion of deoxidants.

The calculation of the exact portion of deoxidants is made upon receipt of the results of chemical analysis of the metal in the converter before tapping. The calculation is made for the types of ferroalloys selected by broad-brush calculation.

The calculation is also performed in case of obtaining only carbon content and steel temperature at turndown. Thus, "pattern" melting is selected (Table 1) by actual values of C_M and t_M and the expected value of Mn_M by the array of "pattern" melting after blowing.

In case of disagreement with the calculation (the weight of certain materials) the master has the possibility to adjust it manually by changing the weight in the appropriate windows. To do this in the "Recalculate ferroalloys" window click "Yes" button. In this case, both values are entered into the array of deoxidants - recommended and adjusted ones, and in an array for printing – only adjusted one. In case of consent with the calculation of deoxidants “No” button is pressed. And calculation of deoxidants is printed.

After calculating the exact portion of deoxidants adjusting values of materials in the system of ferroalloys portioning are shown. Adjusting values are determined as the difference between the calculated and the uploaded amount of materials.

The weight of all deoxidants that do not pass through the feeder scales is entered by the master after metal tapping into the ladle. To do this, the form for calculation of ferroalloys is called and “Actual” window is activated. After entering the actual values “No” button is pressed in the “Recalculatie ferroalloys” window. Upon obtaining of metal chemical composition after deoxidation, the coefficients of elements assimilation in the melting are calculated by the formula:

$$b_R^0 = 1 - \frac{0,9(\grave{o}_{\text{ë}} + \grave{o}_{\div})(R_{\text{ð}} - R_{\text{ì}})}{m_{\text{ôñ}} \cdot R_{\text{ôñ}}}, \qquad (6)$$

where $R_{\text{р}}$ - an element content in the metal after deoxidation, %; $m_{\text{фс}}$ - the weight of deoxidant for the element *R*.

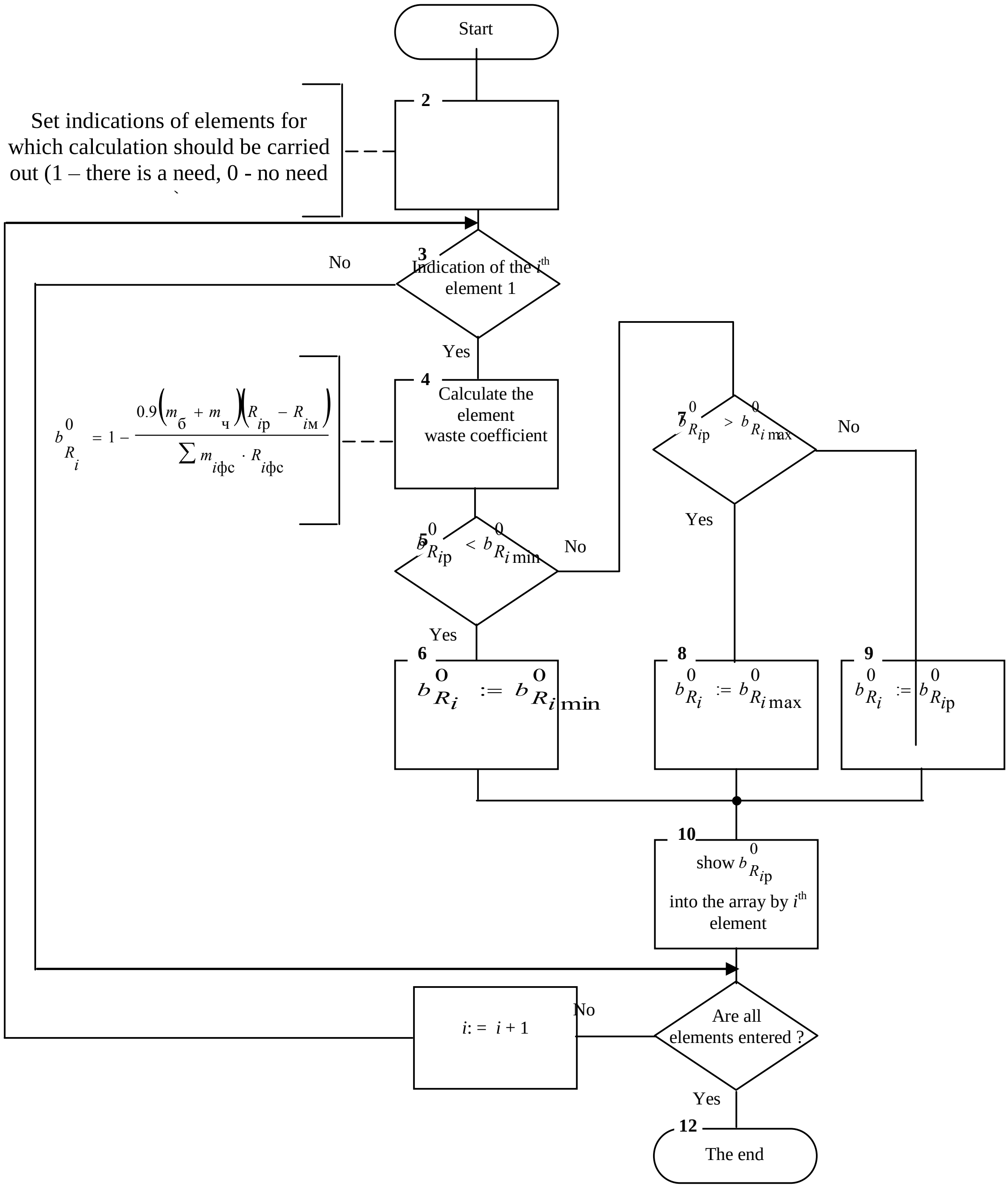


Figure 1. Calculation of the elements assimilation coefficients.

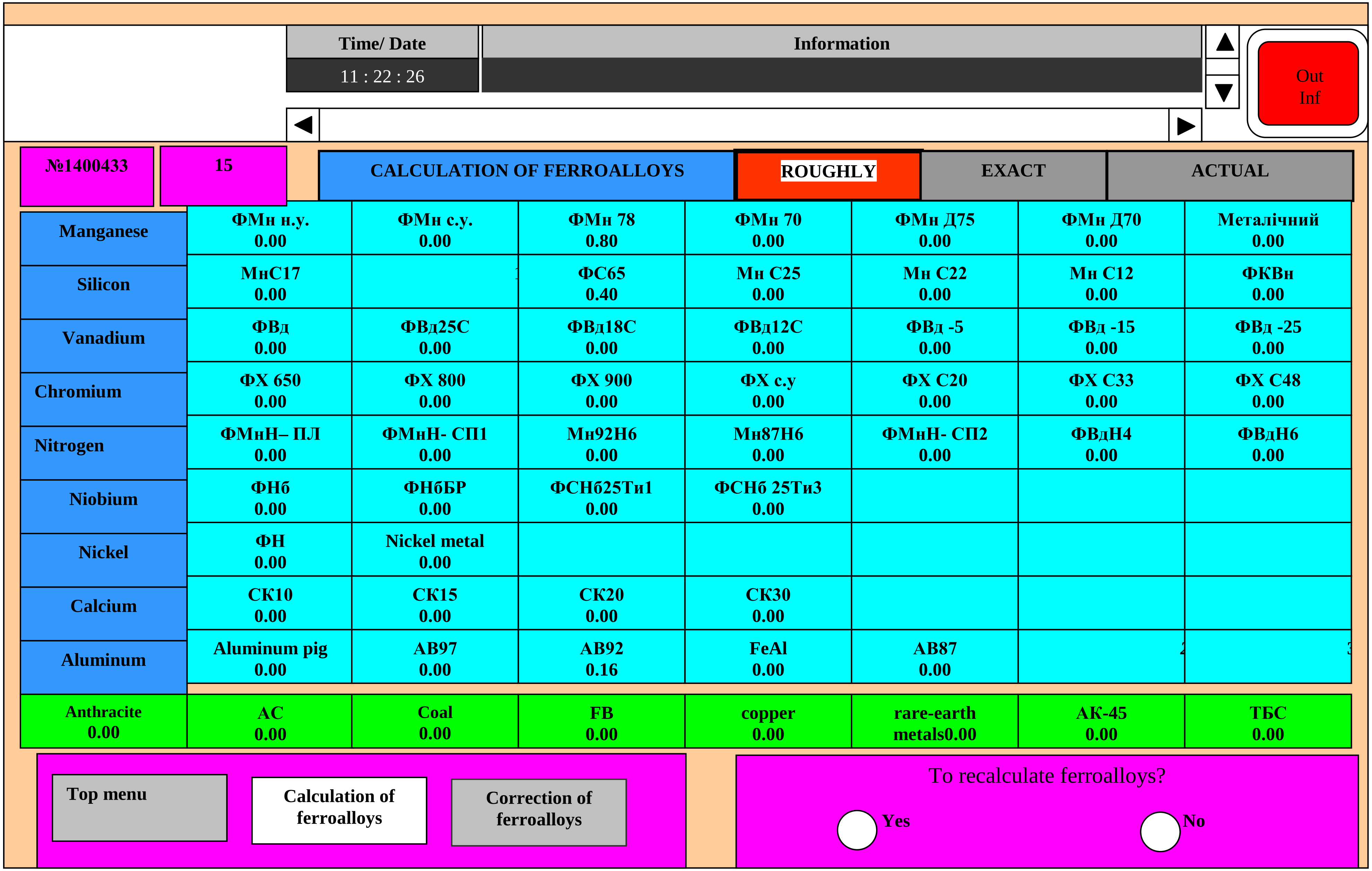
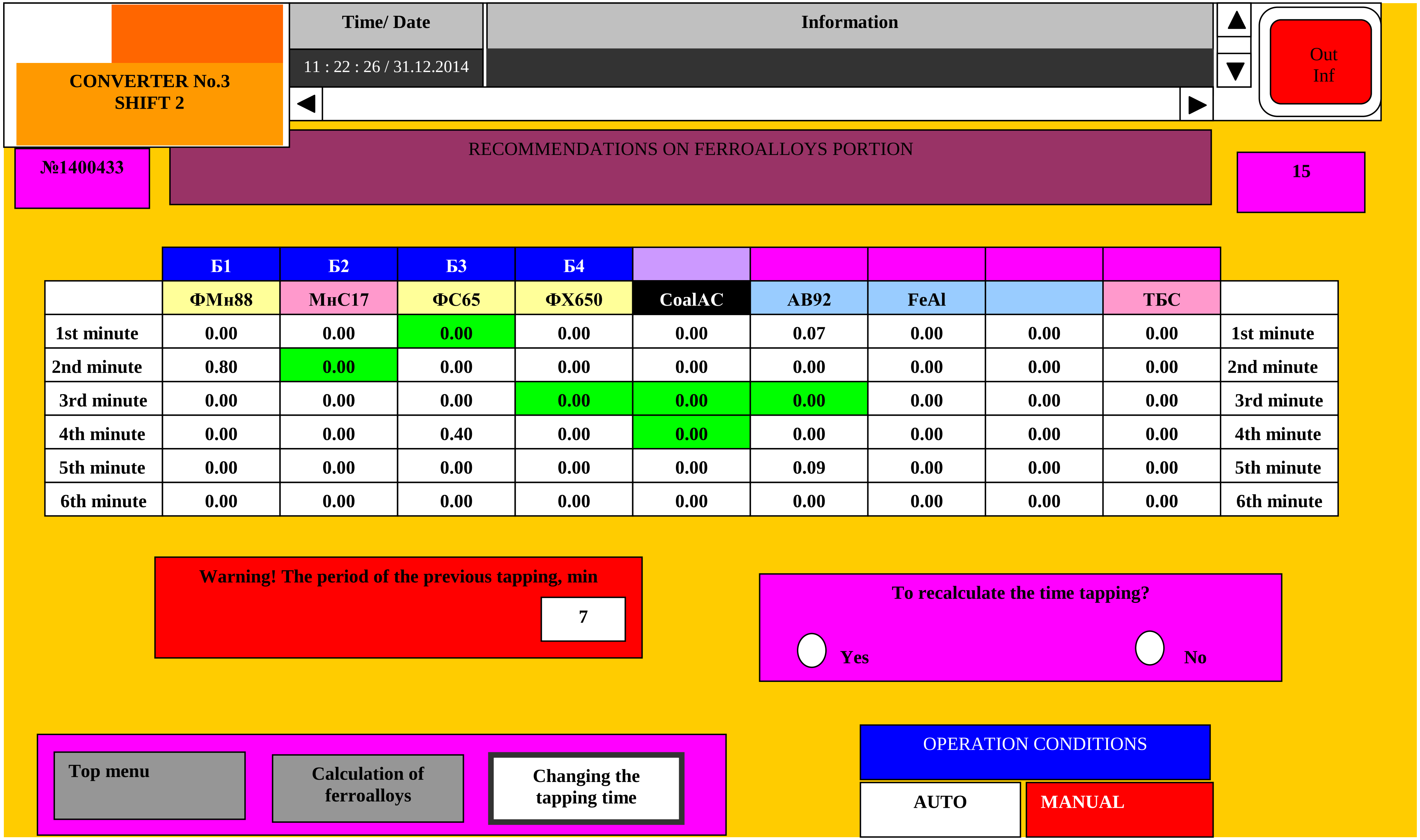


Figure 2. The video frame “Calculation of ferroalloys”



	Б1	Б2	Б3	Б4						
	ФМн88	МнС17	ФС65	ФХ650	CoalAC	AB92	FeAl		ТБС	
1st minute	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	1st minute
2nd minute	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2nd minute
3rd minute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3rd minute
4th minute	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	4th minute
5th minute	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	5th minute
6th minute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6th minute

Figure 3. Video frame “Weight of ferroalloys”

Before entering a “pattern” into an array of melts b_R^0 is checked for the limits of change. If b_R^0 does not come within the limits of change, its old value remains. Originally, average values of waste coefficients for each type of deoxidants are recorded in an array.

For portioning of ferroalloys distributor machinist activates the “Ferroalloys portioning” button on “Ferroalloys calculation” video frame. This forms the setting in the control system “Portion” on ferroalloys portioning (with the distribution by feeds). The procedure for introducing deoxidants in the ladle set by technological instruction is taken into account (Table 2).

Portioning ferroalloys begins on the distributor machinist command in the control system “Portion”.

Table 2. Time to start adding material into the ladle from the start of tapping

Material	Time to start adding material, c, with a duration of tapping, min				
	5	6	7	8	9
Silicocalcium, carburizer	10 – 30	20 – 30	30 – 40	40 – 50	50 – 60
Solid slag former, flux-deoxidant АК-45	40 – 60	60 – 80	80 – 100	100 – 130	130 – 180
Ferroalloys containing Mn, Si, Cr, Ca	80 – 100	100 – 120	120 – 140	140 – 160	160 – 220
Al	120 – 150	140 – 180	170 – 200	190 – 220	220 – 300
Ferroalloys containing Nb, V, Ti, N, REM	160 – 210	200 – 250	230 – 290	250 – 300	280 – 370
The end of the introduction of additives	210 – 230	250 – 270	290 – 310	330 – 350	370 – 460

Features of deoxidants proportioning of certain steel grades

Deoxidation of rimmed steel of grades 3кп, 4кп, 08кп, 10кп, 15кп, 20кп is made by ferromanganese. Steel oxidation is corrected by aluminum or ferroaluminum and coal AC. At the beginning of tapping 50 - 100% is added (the amount is determined by “pattern” melting, in its absence - 50%) of the required amount of aluminum, the rest - during tapping. The coal is added uniformly during tapping.

The calculated amount of aluminum (ferroaluminium) and coal is verified for the limits (Table. 3) and in the case of going beyond the limits, the limit value is accepted.

Table 3: Variation range of aluminum (ferroaluminium) and coal consumption during deoxidation of rimmed steel grades

Carbon content at tapping, %	8. The addition of aluminum (ferroaluminium) and coal, g/t			
	9. Content of manganese before tapping, %			
	≤ 0.09		> 0.10	
	Al /FeAl	coal	Al /FeAl	coal
0.04	350-400/525-600	300-350	300-350/450-525	250-300
0.05	250-300/375-450	300-350	200-230/300-345	230-280
0.06	150-200/225-300	200-250	100-130/150-195	120-160
0.07	100/150	100-150	0-50/0-75	80-100

Note: If the final blow has been made at the middle position of the lance above 1400 mm (heating, sulfur removal, cooling with lime with slag blowing, aluminum (ferroaluminium) consumption increases by 50 (75 g/t of steel).

Semikilled steel is deoxidized by ferromanganese or silicomanganese as well as ferrosilicon. Deoxidation of steel grades 3пс, 5пс, 3Гпс, 3ТРпс, 3ГТРпс, 5Гпс, 35ГСм, 25Г2См is carried out in the ladle with ferromanganese and silicomanganese on the basis of obtaining silicon content of 0.07% and a weight-average proportion of manganese in the finished steel. If it’s not possible to obtain the silicon content of 0.07%, its content within 0.05 - 0.10% is checked. In the absence of silicomanganese final deoxidation of metal is carried out in the ladle by ferromanganese and ferrosilicon.

Microalloying of steel is carried out by titanium or titanobauxite alloy and (or) ferroboron to obtain not more than 0.03 titanium or boron not more than 0.005% in the finished steel.

Deoxidation of steel grades 5пс, 3ТРпс is carried out in the ladle by ferromanganese and ferrosilicon to obtain silicon content of 0.07% and a weight-average proportion of manganese in the finished steel. If it is not possible to obtain the silicon content of 0.07%, its content within 0.05 - 0.10% is checked. In the absence of ferrosilicon deoxidation of metal is carried out in the ladle by silicomanganese and ferromanganese.

Deoxidation of killed steel is carried out by silicomanganese and ferromanganese and 65% or 45% ferrosilicon median rate of receipt of manganese and silicon in the finished steel. Ferroalloys are introduced in the following order: silicomanganese, ferromanganese, ferrosilicon.

Consumption of aluminum or ferroaluminium is for steel grades 1сп and 2сп 1200/1800 g/t of steel; for steel 3сп - 1000/1500 g/t of steel; for steel 5сп 700/1050 g/t of steel. Aluminum (ferroaluminium) is introduced into the ladle in the following order. At the beginning of tapping prior the input to ferroalloys 40 - 50% is added (the amount is determined by “pattern” melting, in its absence - 40%) of the required amount of aluminum, the rest - after addition of ferroalloys.

Deoxidation of steel grades 20ГС, 27ГС, 30ГС, 25Г2С, 35ГС is carried out by silicomanganese and 65%ferrosilicon to obtain eight-average content of manganese and silicon in the finished steel and aluminum (ferroaluminum) of 500 (750) g/t of steel.

Alloying and deoxidation of steel grade 30ХГСА is carried out by ferrochromium, silicomanganese and 65% ferrosilicon to obtain eight-average of chromium, manganese and silicon in the finished steel. The final deoxidation is carried out by aluminum (ferroaluminum) at a rate of 700 (1050) g/t of steel.

Alloying by ferrochromium as well alloying and deoxidation of steel grade 40X is carried out by ferromanganese, silicomanganese and 65% ferrosilicon to obtain weight-average chromium and manganese content in the finished steel.

Deoxidation of killed structural steels. Tapping from the converter is performed at a set carbon content followed by carburizing at not more than 0.12%. Consumption of aluminum (ferroaluminium) is, g/t of steel: steel 10 - 1200 (1800); 15-20 - 1000 (1500); 25-30 - 800 (1200); 35-55 - 700 (1050); 50Г - 500 (750); 15Х - 700 (1050); 20Х - 500 (750).

Deoxidation of steel 23Г2А is carried out by silicomanganese, ferromanganese, aluminum and ferrotitanium. The order of introducing deoxidants is as follows: at the beginning of tapping silicomanganese is added into the ladle to obtain set-average value of silicon content in the finished steel and ferromanganese to obtain set-average value of manganese content in the finished steel, followed by aluminum and ferrotitanium to obtain 800-1000 g/t of each in steel (numerical value is determined by “pattern” melting, in case of its absence - 900 g/t).

Deoxidation of steel 26ГА, 23ХГА is carried out by silicomanganese and ferrochromium to obtain set-average manganese and chromium content in the finished steel 800-1000 g/t of each (numerical value is determined by “pattern” melting, in case of its absence - 900 g/t).

To obtain carbon content towards the lower limit in the finished steel, carbon content before tapping ain the process of alloying steel grade ФХ650 – ФК850 by ferrochrome should be in the range of 0.06 - 0.12%.

Deoxidation of steel 09Г2 is carried out by ferromanganese, silicomanganese and aluminum (ferroaluminum) at a rate of 800 (1200) g/t of steel, and steel 09Г2С – by silicomanganese, 65% ferrosilicon and aluminum (ferroaluminum) at a rate of 500 (750) g/t of steel.

Deoxidation of steels НП-30ХГСА and НП-26ХГСА is carried out by ferrochrome, silicomanganese and 65% ferrosilicon to obtain set-average content of chromium, manganese and silicon in the finished steel. Aluminum (ferroaluminium) is introduced into the ladle after addition of ferroalloys in the amount of 700 (1050) g/t of steel НП-30ХГСА, and 500 (750)g/t of steel НП-26ХГСА.

Deoxidation of steels Св-08ГС and Св-08Г2С is carried out by silicomanganese to obtain weight-average manganese content and by 65% ferrosilicon. Aluminum (ferroaluminium) is instroduced into the ladle after the addition of all ferroalloys at a rate of 500 (750) g/t of steel.

Deoxidation of steel Св-08Гis carried out by medium-carbon ferromanganese to obtain weight-average manganese content. Aluminum (ferroaluminium) onsumption is 1300 (1950) g/t of steel.

The melts are tapped from the converter with carbon content not exceeding 0.05%.

Deoxidation of rope steel grades is carried out by silicomanganese and 65% ferrosilicon of the weight average calculation software of manganese and silicon.

The melts are tapped from the converter when the carbon content does not exceed 0.20% below the weight-average carbon content in the rope steel grades.

Deoxidation of steel grade 10кп with a high content of aluminum is carried out by ferromanganese to ensure weight-average manganese content steel and aluminum in the finished in the amount of 300 kg per melt.

The melts are tapped from the converter when carbon content is not less than 0.07%.

Deoxidation of 10 кп and 0м steel grades in nearlyrimming steel is carried out by silicomanganese and ferromanganese, depending on the residual carbon, kg/melt (Table 4).

The calculation of silicomanganese and ferromanganese is carried out referenced to “pattern” melting, in case of its absence it’s recommended to use weight-average value of the corresponding column. When the melt is tapped from one turndown silicomanganese consumption corresponds to the lower limit.

Table 4: Deoxidants consumption in the production of 1кп and 0м steel grades.

Deoxidants	Residual carbon before tapping, %						
	0.03	0.04	0.05	0.06	0.07	0.08	0.09
iMn	1000	800-900	500-800	500-700	500-700	500-700	500-700
FeMn	200-300	200-400	200-400	200-400	200-400	200-400	200-400
Al/FeAl	90/110	90/110	45/65	25/45	-	-	-
Coal AC	20-60	20-40	0-20	0-20	-	-	-

Aluminum (ferroaluminium) is introduced into the ladle immediately after the start of tapping. In the case of final blowing of the melt at integral mean lance position not higher than 1400 mm and more than two turndowns aluminum consumption increases by 20 kg per melting.

Deoxidation of Св08 and Св08А steel grades is carried out by silicomanganese, ferromanganese and titanium-aluminum briquettes, depending on the residual carbon, kg/melt (Table 5).

Table 5: Flow rate of deoxidants in the smelting of Св08 and Св08А steel grades.

Deoxidants	Residual carbon before tapping, %				
	0.04	0.05	0.06	0.07	0.08
SiMn	650-800	550-700	550-650	550-650	500-600
FeMn	500-700	500-650	480-600	400-550	300-460
ТАБ	90-105	45-70	30-50	15	-
Coal AC	0-40	20-40	0-20	-	-
Titanobauxite alloy	80-100	80-100	-	-	-

Calculation of silicomanganese, ferromanganese, titanium-aluminum briquettes and coal is carried out referenced to the “pattern” melting, in the case of its absence it is recommended to use weight-average value of the corresponding column.

In case of final blowing at the integral mean lance position above 1400 mm and/or more than two turndown the consumption of titanium-aluminum briquettes increases by 20 kg per melting.

Together with the titanium-aluminum briquettes oxidation adjustment is carried out by ferroaluminum referenced to the “pattern” melting, in case its absence it is recommended to use weight-average value of the corresponding column (Table 6).

Table 6: FeAl consumption in the melting of Св08 and Св08А steel grades

Deoxidant	Residual carbon before tapping, %	
	less than 0.06	0.06 and more
FeAl	24-26	16-18

Titanobauxite alloy is introduced immediately after the beginning of tapping, titanium-aluminum briquettes and FeAl – prior to the beginning of ferroalloys introduction. Addition of silicomanganese, ferromanganese and coal begins when the ladle is filled with metal by 1/5 and ends when it’s filled by 2/3 of its height.

In the absence of titanium-aluminum briquettes deoxidation of Св08 and Св08А steel grades is carried out in accordance with the deoxidation of rimmed steel grades.

Deoxidation of semi-killed of low-alloy steel 25Г2С with chromium is carried out by silicomanganese, ferromanganese to obtain silicon at a rate of < 0.05 and a weight-average manganese content in the finished steel referenced to the “pattern” meltings and ferrochrome in the amount of 300 kg per melting. When using furnace bars made of high-alloy steel instead of ferrochrome ($m_{фх}$, kg), the weight of the bars ($m_{к}$, kg) is detrmined by the furmula:

$$m_{к} = \frac{m_{фх} \cdot R_{фх}}{R_{к}}, \quad (7)$$

where $R_{фх}$, $R_{к}$ - the content of chromium in the ferrochrome and bars, respectively, %. In the absence of chromium content in the bars, its average value of 28% is taken. The resulting value is verified for permissible limits (1000 - 2000 kg) in the event of going beyond the nearest limit value is taken.

Carbon content at metal tapping should not be less than 0.05%.

Deoxidation of steel grades 3ТРпс, 3ГТРпс according to the national standards of Ukraine, Germany and the UK is carried out by ferromanganese and ferrosilicon referenced to the “pattern” melting; in case of its absence - in accordance with the calculation of deoxidants for semi-killed steel. For 3ТРпс grade results of the calculation are verified for the maximum possible values (Table 7). In case of exceeding it is recommended to use values from the Table.

Table 7: Maximum deoxidants consumption in the smelting of steel 3ТРпс

Deoxidant	Residual carbon before tapping,%				
	less than 0,05	0,05	0,06	0,07	0,08 and more
FeMn	1450	1400	1350	1300	1150
FeSi 65 %	300	250	250	250	200

Deoxidation of 3ТрпсУ steel grade is carried out by ferromanganese and ferrosilicon or ferromanganese and silicomanganese referenced to the “pattern” melting; in the case of its absence the calculation is carried out on the basis of conditions for ensuring weight-average manganese content in the finished steel and silicon content of 0.07%. The resulting value of siliceous materials is verified for permissible limits (Table 8) and in case of going beyond the limits the nearest limit value is taken.

Table 8: Maximum deoxidants consumption in the smelting of 3ТРпс steel grade

Ferroalloys, kg/melt	8. Residual carbon before tapping, %			
	0.03-0.05	0.06-0.09	0.10-0.13	0.14-0.20
FeSi 65 %	300-400	200-300	150-200	100-150
SiMn	1100-1400	900-1100	700-900	500-700

In case of tapping 3ТРпс and 3ГТРпс steel grades with a carbon content less than 0.07 pre-adjustment of oxidation titanobauxite alloy is carried out. Its amount is determined by “pattern” melting; if it is missing 90 kg/melting is recommended. Titanobauxite alloy is introduced into the ladle immediately after the start of tapping.

Deoxidation of 25ХГНМА steel grade is carried out by ferrosilicon, silicomanganese, carbon ferrochromium, ferrotitanium and aluminum referenced to the “pattern” melting, in case of its absence the calculation is carried out based on the conditions for ensuring the mean-manganese, silicon, chromium, and titanium, and aluminum is added in an amount of 1.9 kg/t of steel. Alloying of the steel is carried out by ferronickel which is directly introduced on the metal waste, and by ferromolybdenum which is introduced immediately after primary flushing. The amount of alloying elements is determined by melting "positive experience melting operations", in the case of its absence - the calculation is made a condition for the mean-molybdenum and nickel with a degree of assimilation of 95 and 97%, respectively.

The model was tested at Azovstal Iron and Steel Works PJSC and Yenakiieve Iron and Steel Works. Testing havs shown that deoxidants saving is 2.5% in average.

Conclusions

1. Waste of deoxidant and alloying elements varies greatly depending on the carbon and manganese content, metal temperature and steel grade.
2. Control of the deoxidation process referenced to the “pattern” melting significantly improves economic performance of the converter process.

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