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MATERIAL BALANCE MODEL FOR STEEL PRODUCTION IN ELECTRIC ARC FURNACE - OXIDATION PERIOD

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ABSTRACT

The oxidation period represents the middle stage of the calculation model concerning the production of bearing steel. The creation of this steel can take place in a high temperature furnace. This modelling is done using the knowledge that metallurgical practice gives us and the formulated dependences in the melting period model, published earlier in the journal. The data for slag, metal and gas phases, as well as the material balance of the period, at the end of the development, were calculated using the dependencies in this model.

Keywords: production of steel in electric arc furnace, oxidation period.

INTRODUCTION

An essential point for the considered steel is a minimum amount of oxide and sulfide inclusions. For minimal amounts of oxide inclusions, it is necessary during the oxidation period to treat the metal (for pre-deoxidation) with silicomanganese at the end of the period. The content of sulfide inclusions is determined by the sulfur content of the finished metal. Low sulfur content can be obtained by using slag-forming materials with low sulfur content and using slag with a basicity of 3.00 - 3.50 during this period [1, 2].

EXPERIMENTAL

Elemental composition of the metal during the period [1 - 3]

The chemical composition of the elements in the liquid metal at the end of the melting period was presented in a previous issue of the journal (Table 4 of [4]).

According to the calculation model for the melting period, the weight of the metal at the end of the period is assumed to be 97.00 kg ($m_{melt.}^{metal}$) [4]. Thus, the elements are distributed as follows.

It is assumed that carbon will be oxidized for good degassing of the metal so that at the end of the period about 0.80 % C ($\%[C]_{oxid.-end}$) remains in it. Thus the carbon in the metal ($m_{oxid.-end}^{[C]}$) will be:

$$m_{oxid.-end}^{[C]} = m_{melt.}^{metal} \frac{\%[C]^{oxid.-end}}{100}, \text{kg} \qquad (1)$$

at the end of the oxidation period is oxidized (passes into the gas phase) amount of carbon $m_{oxid.-end}^{\{C\}}$ according to the formula:

$$m_{oxid.-end}^{\{C\}} = m_{R}^{r.m.-metal} - m_{oxid.-end}^{[C]}, \text{ kg}, \qquad (2)$$

where: $m_{R}^{r.m.-metal}$ - total amount of non-oxidized element passed in the metal, in relation to carbon, from the charge materials, kg.

It is assumed that at the end of the period about 0.2 % Mn ($\%[Mn]_{oxid.-end}$) will remain in the metal. Thus the manganese in the metal ($m_{oxid.-end}^{[Mn]}$) will be:

$$m_{oxid.-end}^{[Mn]} = m_{melt.}^{metal} \frac{\%[Mn]^{oxid.-end}}{100}, \text{ kg}, \qquad (3)$$

at the end of the oxidation period the amount of manganese $m_{oxid.-end}^{(Mn)}$ is oxidized according to the formula:

$$m_{oxid.-end}^{(Mn)} = m_R^{r.m.-metal} - m_{oxid.-end}^{[Mn]}, \text{ kg} \qquad (4)$$

where: $m_R^{r.m.-metal}$ - total amount of non-oxidized element in the metal, with respect to manganese, from the charge materials, kg.

It is assumed that at the end of the period about 0.03 % Si ($\%[Si]_{oxid.-end}$) will remain in the metal. Thus the silicon in the metal ($m_{oxid.-end}^{[Si]}$) will be:

$$m_{oxid.-end}^{[Si]} = m_{melt.}^{metal} \frac{\%[Si]^{oxid.-end}}{100}, \text{ kg} \qquad (5)$$

at the end of the oxidation period the amount of silicon $m_{oxid.-end}^{(Si)}$ is oxidized according to the formula:

$$m_{oxid.-end}^{(Si)} = m_R^{r.m.-metal} - m_{oxid.-end}^{[Si]}, \text{ kg} \qquad (6)$$

where: $m_R^{r.m.-metal}$ - total amount of non-oxidized element passed in the metal, in relation to silicon, from the charge materials, kg.

It is assumed that at the end of the period about 0.015 % P ($\%[P]_{oxid.-end}$) will remain in the metal. Thus the phosphorus in the metal ($m_{oxid.-end}^{[P]}$) will be:

$$m_{oxid.-end}^{[P]} = m_{melt.}^{metal} \frac{\%[P]^{oxid.-end}}{100}, \text{kg} \qquad (7)$$

at the end of the oxidation period the amount of phosphorus $m_{oxid.-end}^{(P)}$ is oxidized according to the formula:

$$m_{oxid.-end}^{(P)} = m_R^{r.m.-metal} - m_{oxid.-end}^{[P]}, \text{ kg} \qquad (8)$$

where: $m_R^{r.m.-metal}$ - total amount of non-oxidized element in the metal, with respect to phosphorus, from the charge materials, kg.

According to the assumptions and in case of slag content $B \geq 3.0$, as well as by continuous renewal of the slag composition, sulfur will be separated from the metal in the amount of $m_{oxid.-end}^{(S)} = 0.01$ kg. The amount of sulfur ($m_{oxid.-end}^{[S]}$) will remain in the metal:

$$m_{oxid.-end}^{[S]} = m_R^{r.m.-metal} - m_{oxid.-end}^{(S)}, \text{ kg} \qquad (9)$$

where: $m_R^{r.m.-metal}$ - total accepted quantity of non-oxidized element in the metal, with respect to sulfur, from the charge materials, kg.

The technological implementation of the process of obtaining bearing steel requires at the end of the oxidation period to make the so-called preliminary deoxidation of the liquid metal. Therefore, silicomanganese is introduced into it in the amount of $m_{oxid.}^{SiMn} = 0.25$ kg / 100 kg charge. Then, according to chem. composition of SiMn in the metal will be imported elements according to the formula:

$$m_{oxid.}^{SiMn-[R]} = m_{oxid.}^{SiMn} \frac{\%R_{oxid.}^{SiMn}}{100}, \text{ kg} \qquad (10)$$

where: $m_{oxid.}^{SiMn-[R]}$ - mass of silicomanganese elements passing into the metal at the end of the oxidation period, such as R - C, Si, Mn, P, S and Fe, kg; $\%R_{oxid.}^{SiMn}$ - percentage of participation of the element R in the silicomanganese, such as R - C, Si, Mn, P, S and Fe, respectively - 1.00 %, 18.00 %, 67.00 %, 0.08 % , 0.05 % and 13.87 % (from the model for the melting period), %.

Practice has shown that the introduction of $m_{oxid.}^{SiMn} = 0.25$ kg SiMn / 100 kg charge increases the Mn content in steel by 0.1 % ($\%[Mn_{raised}]^{SiMn}$). Therefore, the metal will pass:

$$m_{oxid.}^{SiMn-[Mn\ raised]} = m_{melt.}^{metal} \frac{\%[Mn\ raised]^{SiMn}}{100}, \text{ kg} \qquad (11)$$

and manganese is oxidized in an amount of:

$$m_{oxid.-end}^{(Mn)}{}_{SiMn} = m_{oxid.}^{SiMn-[R]} - m_{oxid.}^{SiMn-[Mn\ raised]}, \text{ kg,} \qquad (12)$$

as $m_{oxid.}^{SiMn-[R]}$ is the amount of element imported with SiMn relative to Mn.

It is also assumed that 40 % of the imported silicon ($\%[Si_{raised}]^{SiMn}$) passes into the metal in an amount of:

$$m_{oxid.}^{SiMn-[Si\ raised]} = m_{oxid.}^{SiMn-[R]} \frac{\%[Si\ raised]^{SiMn}}{100}, \text{ kg} \qquad (13)$$

as $m_{oxid.}^{SiMn-[R]}$ is the amount of element imported with silicomanganese in relation to silicon, and silicon is oxidized in the amount of:

$$m_{oxid.-end}^{(Si)}{}_{SiMn} = m_{oxid.}^{SiMn-[R]} - m_{oxid.}^{SiMn-[Si\ raised]}, \text{ kg,} \qquad (14)$$

as $m_{oxid.}^{SiMn-[R]}$ is the amount of element imported with silicomanganese relative to silicon.

Determination of the amount of slag in the oxidation period [1 - 3]

According to Eq. (8), an amount of phosphorus $m_{oxid.\text{-}end}^{(P)}$ is oxidized from the metal and goes into the slag. The release of phosphorus, with increasing temperature of the metal, decreases approximately in proportion to the decarburization. This is strongly influenced by the constant renewal of the slag, by pouring the old and the formation of new slag. Thus, the average content of P_2O_5 in the slag can be assumed to be 0.5 % ($\%P_2O_{5\text{-}oxid.}^{slag}$). Thus, the total amount of slag is:

$$m_{oxid.}^{slag} = \frac{m_{oxid.-end}^{(P)}}{\%P2O5_{-oxid.}^{slag}} \frac{M_{P2O5}}{M_{P2}} 100, \text{ kg} \qquad (15)$$

where: M_{P2O5} - molecular weight of P_2O_5; M_{P2} - molecular weight of P_2.

Determining the amount of iron ore [1 - 3]

The source of oxygen for oxidation of the elements during the period is FeO, which is obtained from Fe_2O_3 of iron ore by the reaction $Fe_2O_3 + Fe = 3FeO$.

Table 1 shows the amount of FeO according to the reactions with the impurities required for their oxidation.

To form $m_{FeO}^{oxid.\text{-}C,Si,Mn,P}$, an amount of Fe_2O_3 ($m_{Fe2O3}^{oxid.\text{-}C,Si,Mn,P}$) is required according to the formula:

$$m_{Fe2O3}^{oxid.-C,Si,Mn,P} = m_{FeO}^{oxid.-C,Si,Mn,P} \frac{M_{Fe2O3}}{M_{FeO} + M_{Fe}}, \text{ kg}, \qquad (16)$$

M_{Fe2O3} - molecular weight of Fe_2O_3; M_{FeO} - molecular weight of FeO; M_{Fe} - molecular weight of Fe.

In addition to the required amount of Fe_2O_3 ($m_{Fe2O3}^{oxid.\text{-}C,Si,Mn,P}$), an amount of iron ($m_{Fe}^{oxid.\text{-}C,Si,Mn,P}$) is required for the formation of $m_{FeO}^{oxid.\text{-}C,Si,Mn,P}$ according to the formula:

$$m_{Fe}^{oxid.-C,Si,Mn,P} = m_{FeO}^{oxid.-C,Si,Mn,P} - m_{Fe2O3}^{oxid.-C,Si,Mn,P}, \text{ kg}. \qquad (17)$$

Amount of FeO required to maintain a certain concentration of slag in the slag [1, 5 - 9]

To reach $\%[C]_{oxid.\text{-}end} = 0.80$ % in the metal, when the slag is basic

$$B = \frac{CaO + MgO + MnO}{SiO2 + ½Al2O3 + ½Fe2O3 + 2P2O5} = 3,$$

it is necessary to maintain determined concentration of oxygen, respectively, iron oxide in the slag.

To determine the oxygen concentration in the slag, the oxygen content of the metal ($\%[O]_{oxid.}^{TD}$) must first be determined. For this purpose, specialized triple diagrams of the state were used, from which it is obtained that

Table 1. Amount of FeO required for oxidation of impurities.

Element	They oxidize, kg	Reaction	Expenditure per unit element	It is necessary FeO, kg
C from metal	$m_{oxid.-end}^{\{C\}}$	FeO + C = = Fe + CO	$\frac{M_{FeO}}{A_C} = c$	$m_{FeO}^{oxid.-C} = m_{oxid.-end}^{\{C\}} . c$
Si from metal	$m_{oxid.-end}^{(Si)}$			
Si from SiMn	$m_{oxid.-end}^{(Si)}{}_{SiMn}$ (total: $m_{oxid.-end}^{(Si)} + m_{oxid.-end}^{(Si)}{}_{SiMn}$)	2FeO + Si = = 2Fe + SiO_2	$\frac{M_{2FeO}}{A_{Si}} = s$	$m_{FeO}^{oxid.-Si} = (m_{oxid.-end}^{(Si)} + m_{oxid.-end}^{(Si)}{}_{SiMn}) . s$
Mn from metal	$m_{oxid.-end}^{(Mn)}$			
Mn from SiMn	$m_{oxid.-end}^{(Mn)}{}_{SiMn}$ (total: $m_{oxid.-end}^{(Mn)}{}_{SiMn} + m_{oxid.-end}^{(Mn)}$)	FeO + Mn = = Fe + MnO	$\frac{M_{FeO}}{A_{Mn}} = m$	$m_{FeO}^{oxid.-Mn} = (m_{oxid.-end}^{(Mn)}{}_{SiMn} + m_{oxid.-end}^{(Mn)}) . m$
P from metal	$m_{oxid.-end}^{(P)}$	5FeO + 2P = = 5Fe + P_2O_5	$\frac{M_{5FeO}}{M_{P2}} = p$	$m_{FeO}^{oxid.-P} = m_{oxid.-end}^{(P)} . p$
Total				$m_{FeO}^{oxid.-C,Si,Mn,P}$

$\%[O]_{oxid.}^{TD} = 0.028$ %, which corresponds to the content of iron oxide - $\%[FeO]_{oxid.}^{TD} = 0.126$ %.

The activity of the slag is found by the formula:

$$a_{FeO} = \frac{\%[O]_{oxid.}^{TD}}{\lg \%[O]_{oxid.}^{TD}}, \qquad (18)$$

where:

$$\%[O]_{oxid.}^{TD} = \frac{6320}{T+2{,}734}, \%, \text{ where:} \qquad (19)$$

$\%[O]_{oxid.}^{TD}$ - concentration of oxygen saturation in the metal at a temperature of 1600°C.

After calculation, it is determined that $\%[O]_{oxid.}^{TD} = 0.23$ and $a_{FeO} = 0.12$.

Thus, again through the triple diagrams, the composition of the oxidizing slag in molar parts can be found, shown in Table 2.

To determine the composition of the slag from molar percentages to mass percentages, we assume an average molecular weight of the sum of basic oxides equal to the molecular weight of CaO (M_{CaO}) and an average molecular weight of the sum of acid oxides equal to the molecular weight of SiO_2 (M_{SiO2}). This determination is presented in Table 3.

The amount of slag determined above - $m_{oxid.}^{slag}$, must contain a certain total amount of FeO ($m_{oxid.}^{(FeO)\text{-}total}$). It is calculated by the formula:

$$m_{oxid.}^{(FeO)-total} = m_{oxid.}^{slag} \frac{m_{(FeO)}^{w.\%}}{100}, \text{kg} \qquad (20)$$

However, the slag remaining from the melting period is about 30 % ($\%Slag^{melt.}$), because about 70 % of it is omitted. Thus, the amount of FeO ($m_{melt.}^{(FeO)\text{-}total}$) released with the slag after the melting period will be:

$$m_{melt.}^{(FeO)-total} = m_{RxOy}^{r.m.-slag} \frac{\%Slag^{melt.}}{100}, \text{kg}, \qquad (21)$$

where $m_{RxOy}^{r.m.\text{-}slag}$ - the amount of oxide of the elements of the charge materials passing into the slag, in relation to FeO ($m_{RxOy}^{r.m.\text{-}slag} = 0.299$, presented in Table 5 in [4]), kg.

Thus, the remaining FeO in the iron ore slag ($m_{oxid.}^{(FeO)\text{-}ore}$) will be in the amount of:

$$m_{oxid.}^{(FeO)\text{-}ore} = m_{oxid.}^{(FeO)\text{-}total} - m_{melt.}^{(FeO)\text{-}total}, \text{kg} \qquad (22)$$

The formation of this FeO requires an amount of Fe_2O_3 ($m_{oxid.}^{(Fe2O3\rightarrow FeO)\text{-}ore}$), calculated by the formula:

$$m_{oxid.}^{(Fe2O3\rightarrow FeO)-ore} = m_{oxid.}^{(FeO)-ore} \frac{M_{Fe2O3}}{100}, \text{kg} \qquad (23)$$

Thus, the required iron ($m_{oxid.}^{(Fe\rightarrow FeO)\text{-}ore}$) for the formation of FeO will be:

$$m_{oxid.}^{(Fe\rightarrow FeO)\text{-}ore} = m_{oxid.}^{(FeO)\text{-}ore} - m_{oxid.}^{(Fe2O3\rightarrow FeO)\text{-}ore}, \text{kg} \qquad (24)$$

Amount of FeO that dissolves in liquid steel [1, 5 - 9]

The required content of FeO in the metal was determined above - $\%[FeO]_{oxid.}^{TD}$. At the end of the melting period, the metal is assumed to contain between 0.050 and 0.070 % FeO (average 0.060 % - $\%[FeO]_{melt.\text{-}end}$) [4]. To ensure $\%[FeO]_{oxid.}^{TD}$ it is necessary to add a certain amount of FeO ($[FeO]_{oxid.}^{adding}$) according to the formula:

$$\%[FeO]_{oxid.}^{adding} = \%[FeO]_{oxid.}^{TD} - \%[FeO]_{melt.\text{-}end}, \%. \qquad (25)$$

According to Table 4 of [4] and (25), the mass of FeO to be added will be:

$$[FeO]_{oxid.}^{adding} = m_{melt.}^{metal} \frac{\%[FeO]_{oxid.}^{adding}}{100}, \text{kg}. \qquad (26)$$

This requires Fe_2O_3 in quantity ($[Fe_2O_3]_{oxid.}^{adding}$):

Table 2. Composition of oxidizing slag in mole % and mole parts at $a_{(FeO)} = 0.12$.

Oxides	Molar percentages	Molar parts
FeO	7.0	0.07 ($m.p._{(FeO)}^{oxid.}$)
CaO + MgO + MnO	70.0	0.70 ($m.p._{(CaO,MgO,MnO)}^{oxid.}$)
SiO_2 + ½ Al_2O_3 + ½ Fe_2O_3 + $2P_2O_5$	23.0	0.23 ($m.p._{(SiO2,1/2Al2O3,1/2Fe2O3,2P2O5)}^{oxid.}$)
Total	100	1,00

Table 3. Quantity of slag components in mass percentages.

Oxides	Amount of oxides (g) in 1 mol, g mol^{-1}	Amount of oxides (g) in 100 g of slag, % by weight
FeO	$m_{(FeO)}{}^{1\ mol} = m.p._{(FeO)}{}^{oxid.} \cdot M_{FeO}$	$m_{FeO}{}^{w.\%} = \frac{m_{(FeO)}{}^{1\ mol}}{\frac{m_{(RxOy-total)}{}^{1\ mol}}{100}}$
CaO + MgO + MnO	$m_{(CaO,MgO,MnO)}{}^{1\ mol} = m.p._{(CaO,MgO,MnO)}{}^{oxid.} \cdot M_{CaO}$	$m_{(CaO,MgO,MnO)}{}^{w.\%} = \frac{m_{(CaO,MgO,MnO)}{}^{1\ mol}}{\frac{m_{(RxOy-total)}{}^{1\ mol}}{100}}$
$SiO_2 + ½\ Al_2O_3 +$ $½\ Fe_2O_3 + 2P_2O_5$	$m_{(SiO2,1/2Al2O3,1/2Fe2O3,2P2O5)}{}^{1\ mol} = m.p._{(SiO2,1/2Al2O3,1/2Fe2O3,2P2O5)}{}^{oxid.} \cdot M_{SiO2}$	$m_{(SiO2,1/2Al2O3,1/2Fe2O3,2P2O5)}{}^{w.\%} =$ $= \frac{m_{(SiO2,1/2Al2O3,1/2Fe2O3,2P2O5)}{}^{1\ mol}}{\frac{m_{(RxOy-total)}{}^{1\ mol}}{100}}$
Total	$m_{(RxOy-total)}{}^{1\ mol}$ *	100.00

*$m_{(RxOy-total)}{}^{1\ mol}$ - total amount of all considered oxides in 1 mol, g/mol.

$$[Fe_2O_3]_{oxid.}{}^{adding} = [FeO]_{oxid.}{}^{adding} \frac{M_{Fe2O3}}{M_{3FeO}}, kg, \tag{27}$$

where: M_{Fe2O3} - molecular mass of Fe_2O_3; M_{3FeO} - molecular mass of 3FeO

For the reduction of Fe_2O_3 by the reaction:

$$Fe_2O_3 + Fe = 3FeO \tag{28}$$

iron will be needed in quantity ($[Fe]_{oxid.}{}^{Fe2O3-adding}$):

$$[Fe]_{oxid.}{}^{Fe2O3-adding} = [FeO]_{oxid.}{}^{adding} - [Fe_2O_3]_{oxid.}{}^{adding}, kg. \tag{29}$$

The total requirement of Fe_2O_3 ($Fe_2O_{3oxid.}{}^{total}$) is:

$$Fe_2O_{3oxid.}{}^{total} = m_{Fe2O3}{}^{oxid.-C,Si,Mn,P} + m_{oxid.}{}^{(Fe2O3\rightarrow FeO)-ore} + [Fe_2O_3]_{oxid.}{}^{adding}, kg. \tag{30}$$

The consumption of Fe to form FeO ($Fe_{oxid.}{}^{total}$) will be:

$Fe_{oxid.}{}^{total} = m_{Fe}{}^{oxid.-C,Si,Mn,P} + m_{oxid.}{}^{(Fe\rightarrow FeO)-ore} + [Fe]_{oxid.}{}^{Fe2O3-adding}$, kg (this amount of iron is subtracted from the composition of the metal at the end of the oxidation period, see point 8, Table 6). (31)

To determine the amount of iron ore($m_{ore}{}^{oxid.}$), it is assumed that 10 % of Fe_2O_3 passes into the slag and 90 % is reduced to FeO, which contains 90 % Fe_2O_3 (see Table 4). So the ore will be calculated by the formula:

$$m_{ore}{}^{oxid.} = Fe_2O_{3\,oxid.}{}^{total} \frac{100}{\frac{90\ .\ 90}{100}}, kg. \tag{32}$$

Amount of the lime for the oxidation period [1, 5, 6]

From Table 4, it was determined that the CaO + MgO + MnO in the oxidation period slag should be $m_{(CaO,MgO,MnO)}{}^{w.\%}$ %.

The composition of the slag at the end of the melting period is shown in Table 4 of [4]. Only 30 % of it goes into the oxidation period.

Manganese oxide is imported

From the slag of the melting period. It is in the amount of 5.904 kg ($m_{melt.}{}^{slag}$), according to the model for the melting period, taking into account that only 30 % of it goes to the oxidation period [4]. Thus, the amount of ($m_{(MnO)}{}^{melt.\rightarrow oxid.}$) from the melting period that will pass to the slag in the oxidation period will be:

$$m_{(MnO)}{}^{melt.\rightarrow oxid.} = m_{melt.}{}^{slag} \frac{30}{100} \frac{\%MnO_{-oxid.}{}^{melt.-slag}}{100}, kg, \tag{33}$$

where $\%MnO_{-oxid.}{}^{melt.-slag}$ - percentage of MnO participation in the slag from the melting period, %.

The amount ($m_{[Mn]\rightarrow(MnO)}{}^{oxid.}$) of oxidized manganese from the metal is found by the formula:

$$m_{[Mn]\rightarrow(MnO)}{}^{oxid.} = (m_{oxid.-end}{}^{(Mn)} - m_{oxid.-end}{}^{(Mn)}{}_{SiMn}) \frac{M_{MnO}}{M_{Mn}}, kg \tag{34}$$

where: M_{MnO} - molecular mass of MnO; M_{Mn} - molecular mass of Mn.

Thus, total MnO is introduced in the amount ($m_{(MnO)}^{\text{oxid.}\rightarrow\text{slag}}$):

$$m_{(MnO)}^{\text{oxid.}\rightarrow\text{slag}} = m_{(MnO)}^{\text{melt.}\rightarrow\text{oxid.}} + m_{[Mn]\rightarrow(MnO)}^{\text{oxid.}}, \text{ kg.} \tag{35}$$

Magnesium oxide is imported

From the slag of the melting period. The amount of MgO ($m_{(MgO)}^{\text{melt.}\rightarrow\text{oxid.}}$) from the melting period that will pass to the slag in the oxidation period will be:

$$m_{(MgO)}^{\text{melt.}\rightarrow\text{oxid.}} = m_{\text{melt.}}^{\text{slag}}\,\frac{30}{100}\,\frac{\%MgO_{-\text{oxid.}}^{\text{melt.}-\text{slag}}}{100}, \text{ kg} \tag{36}$$

where $\%MgO_{-\text{oxid.}}^{\text{melt.-slag}}$ - percentage of MgO participation in the slag from the melting period, %.

From the iron ore in the amount of $m_{(MgO)}^{\text{ore-oxid.}}$:

$$m_{(MgO)}^{\text{ore}-\text{oxid.}} = m_{\text{ore}}^{\text{oxid.}}\,\frac{\%MgO_{-\text{oxid.}}^{\text{ore}-\text{slag}}}{100}, \text{ kg} \tag{37}$$

where: $\%MgO_{-\text{oxid.}}^{\text{ore-slag}}$ - percentage of MgO participation in iron ore (Table 4), %;

From the floor and walls in quantity ($m_{(MgO)}^{\text{f. and w.-oxid.}}$):

$$m_{(MgO)}^{\text{f. and w.}-\text{oxid.}} =$$

$$= m_{\text{oxid.}}^{\text{magnesite}-\text{slag}}\,\frac{\%MgO_{-\text{oxid.}}^{\text{f. and w.}-\text{slag}}}{100}, \text{ kg} \tag{38}$$

where: $m_{\text{oxid.}}^{\text{magnesite-slag}}$ - amount (1.00 kg) of parts of the furnace floor and walls from the oxidation period passing into the slag (from [4]), kg; $\%MgO_{-\text{oxid.}}^{\text{f. and w.-slag}}$ - percentage of magnesium oxide in the floor and walls of the furnace (Table 4), %;

If we denote the quantity of the lime with $m_{\text{lime-slag}}^{\text{oxid.}}$, then it brings MgO in an amount ($m_{(MgO)}^{\text{lime-oxid.}}$):

$$m_{(MgO)}^{\text{lime}-\text{oxid.}} = m_{\text{lime}-\text{slag}}^{\text{oxid.}}\,\frac{\%MgO_{-\text{oxid.}}^{\text{lime}-\text{slag}}}{100} \text{ kg} \tag{39}$$

where: $\%MgO_{-\text{oxid.}}^{\text{lime-slag}}$ - percentage of magnesium oxide in the slag (Table 4), %;

Thus, total MgO is introduced in the amount ($m_{(MgO)}^{\text{oxid.}\rightarrow\text{slag}}$):

$$m_{(MgO)}^{\text{oxid.}\rightarrow\text{slag}} = m_{(MgO)}^{\text{melt.}\rightarrow\text{oxid.}} + m_{(MgO)}^{\text{ore-oxid .}} + \\ + m_{(MgO)}^{\text{f. and w.-oxid.}} + m_{(MgO)}^{\text{lime-oxid.}}, \text{ kg.} \tag{40}$$

Calcium oxide is imported

From the slag of the melting period. The amount of CaO ($m_{(CaO)}^{\text{melt.}\rightarrow\text{oxid.}}$) from the melting period that will pass to the slag in the oxidation period will be:

$$m_{(CaO)}^{\text{melt.}\rightarrow\text{oxid.}} = m_{\text{melt.}}^{\text{slag}}\,\frac{30}{100}\,\frac{\%CaO_{-\text{oxid.}}^{\text{melt.}-\text{slag}}}{100}, \text{ kg} \tag{41}$$

where $\%CaO_{-\text{oxid.}}^{\text{melt.-slag}}$ - percentage of CaO participation in the slag from the melting period, %.

From the iron ore in the amount of $m_{(CaO)}^{\text{ore-oxid.}}$:

$$m_{(CaO)}^{\text{ore}-\text{oxid.}} = m_{\text{ore}}^{\text{oxid.}}\,\frac{\%CaO_{-\text{oxid.}}^{\text{ore}-\text{slag}}}{100}, \text{ kg} \tag{42}$$

where: $\%CaO_{-\text{oxid.}}^{\text{ore-slag}}$ - percentage of CaO participation in the iron ore (Table 4), %;

From the vault in quantity ($m_{(CaO)}^{\text{v.-oxid.}}$):

$$m_{(CaO)}^{\text{v.}-\text{oxid.}} = m_{\text{oxid.}}^{\text{dinas}-\text{slag}}\,\frac{\%CaO_{-\text{oxid.}}^{\text{v.}-\text{slag}}}{100}, \text{ kg} \tag{43}$$

where: $m_{\text{oxid.}}^{\text{dinas-slag}}$ - amount (0.20 kg) of parts of the furnace vault from the oxidation period passing into the slag (from [4]), kg; $\%CaO_{-\text{oxid.}}^{\text{v.-slag}}$- percentage of CaO participation in the vault of the furnace (Table 4), %;

The lime with an amount of $m_{\text{lime-slag}}^{\text{oxid.}}$ introduces CaO in quantity ($m_{(CaO)}^{\text{lime-oxid.}}$):

$$m_{(CaO)}^{\text{lime}-\text{oxid.}} = m_{\text{lime}-\text{slag}}^{\text{oxid.}}\,\frac{\%CaO_{-\text{oxid.}}^{\text{lime}-\text{slag}}}{100}, \text{ kg} \tag{44}$$

where: $\%CaO_{-\text{oxid.}}^{\text{lime-slag}}$ - percentage of CaO participation in the pit (Table 4), %;

Thus, the total amount of CaO is introduced ($m_{(CaO)}^{\text{oxid.}\rightarrow\text{slag}}$):

$$m_{(CaO)}^{\text{oxid.}\rightarrow\text{slag}} = m_{(CaO)}^{\text{melt.}\rightarrow\text{oxid.}} + m_{(CaO)}^{\text{ore-oxid.}} + m_{(CaO)}^{\text{v.-oxid.}} \\ + m_{(CaO)}^{\text{lime-oxid.}}, \text{ kg.} \tag{45}$$

The following formula is used to find the amount of lime:

$$\begin{aligned} & m_{(MnO)}^{\text{melt.}\rightarrow\text{oxid.}} + \\ & m_{[Mn]\rightarrow(MnO)}^{\text{oxid.}} + m_{(MgO)}^{\text{melt.}\rightarrow\text{oxid.}} + m_{(MgO)}^{\text{ore}-\text{oxid.}} + \\ & + m_{(MgO)}^{\text{f. and w.}-\text{oxid.}} + m_{(CaO)}^{\text{melt.}\rightarrow\text{oxid.}} + \\ & + m_{(CaO)}^{\text{ore}-\text{oxid.}} + m_{(CaO)}^{\text{v.}-\text{oxid.}} + \left[\left(\frac{\%MgO_{-\text{oxid.}}^{\text{lime}-\text{slag}}}{100} + \right.\right. \\ & = m_{\text{oxid.}}^{\text{slag}}\,\frac{m_{(CaO,MgO,MnO)}^{\text{w.\%}}}{100} \\ & \left.\left. + \frac{\%CaO_{-\text{oxid.}}^{\text{lime}-\text{slag}}}{100}\right) m_{\text{lime}-\text{slag}}^{\text{oxid.}}\right] = \\ & = m_{\text{oxid.}}^{\text{slag}}\,\frac{m_{(CaO,MgO,MnO)}^{\text{w.\%}}}{100}, \text{ kg} \end{aligned} \tag{46}$$

Thus the required lime will be:

$$m_{lime-slag}{}^{oxid.} =$$

$$= \frac{m_{oxid.}{}^{slag}\,\frac{m_{(CaO,MgO,MnO)}{}^{w.\%}}{100} - (m_{(MnO)}{}^{melt.\rightarrow oxid.} + m_{[Mn]\rightarrow(MnO)}{}^{oxid.} + m_{(MgO)}{}^{melt.\rightarrow oxid.} +}{\frac{3,30}{100} + \frac{92,00}{100}}$$

$$\frac{+ m_{(MgO)}{}^{ore-oxid.} + m_{(MgO)}{}^{f.\ and\ w.-oxid.} + m_{(CaO)}{}^{melt.\rightarrow oxid.} + m_{(CaO)}{}^{ore-oxid.} + m_{(CaO)}{}^{v.-oxid.}}{\frac{3,30}{100} + \frac{92,00}{100}}, \text{kg} \qquad (47)$$

Composition and amount of slag from the oxidation period [1 - 3, 8, 10]

The remainder (30 %) of the slag of the melting period can be denoted as $m_{slag}{}^{melt.\rightarrow oxid.}$ [4]. This quantity is found by the formula:

$$m_{slag}{}^{melt.\rightarrow oxid.} = m_{melt.}{}^{slag}\,\frac{30}{100}, \text{kg} \qquad (48)$$

The quantity of the remaining oxides ($m_{(RxOy)}{}^{melt.\rightarrow oxid.}$) from the slag from the melting period passing into the slag from the oxidation period is calculated by:

$$m_{(RxOy)}{}^{melt.\rightarrow oxid.} = m_{slag}{}^{melt.\rightarrow oxid.}\,\frac{\%RxOy_{-oxid.}{}^{melt.-slag}}{100}$$

kg (49)

where: $\%RxOy_{-oxid.}{}^{melt.-slag}$ - percentage of participa-tion, respectively, of SiO_2, Al_2O_3, FeO, Fe_2O_3 and P_2O_5 in the slag from the melting period, %.

The amount of metal and silicomanganese elements ($m_{(Si)}{}^{metal+SiMn}$, $m_{(Mn)}{}^{metal+SiMn}$, $m_{(P)}{}^{metal+SiMn}$) that are oxidized until the end of the oxidation period and pass into the slag are calculated using the formulas :

$$m_{(Si)}{}^{metal+SiMn} = (m_{oxid.-end}{}^{(Si)} + m_{oxid.-end}{}^{(Si)}{}_{SiMn})\,\frac{M_{SiO_2}}{M_{Si}}$$

kg (50)

$$m_{(Mn)}{}^{metal+SiMn} = (m_{oxid.-end}{}^{(Mn)} + m_{oxid.-end}{}^{(Mn)}{}_{SiMn})\,\frac{M_{MnO}}{M_{Mn}}$$

kg (51)

$$m_{(P)}{}^{metal+SiMn} = m_{oxid.-end}{}^{(P)}\,\frac{M_{P_2O_5}}{M_{P_2}}, \text{kg} \qquad (52)$$

The quantity of the remaining oxides ($m_{(RxOy)}{}^{ore-oxid.}$) from the iron ore (without H_2O – passing into the gas phase), passing into the slag from the oxidation period, is calculated by:

$$m_{(RxOy)}{}^{ore-oxid.} = m_{ore}{}^{oxid.}\,\frac{\%RxOy_{-oxid.}{}^{ore-slag}}{100}, \text{kg} \qquad (53)$$

where: $\%RxOy_{-oxid.}{}^{ore-slag}$ - percentage of participation, respectively, of SiO_2, Al_2O_3, Fe_2O_3 and P_2O_5 in the pit (Table 4), %.

As stated in point **Amount of FeO that dissolves in liquid steel**, 10 % of the Fe_2O_3 from the iron ore passes into the slag. The number thus obtained for Fe_2O_3, according to (53), must be multiplied by 10/100.

The amount of FeO was calculated in point 4 and is $m_{oxid.}{}^{(FeO)-ore}$.

- The amount of oxides ($m_{(RxOy)}{}^{lime-oxid.}$) from the lime (without CO_2 and H_2O - passing into the gas phase), passing into the slag from the oxidation period, is calculated by:

$$m_{(RxOy)}{}^{lime-oxid.} = m_{lime-slag}{}^{oxid.}\,\frac{\%RxOy_{-oxid.}{}^{lime-slag}}{100}, \text{kg}, \qquad (54)$$

where $\%RxOy_{-oxid.}{}^{lime-slag}$ - percentage of participation, respectively, of CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3, P_2O_5 and S in the pit (Table 4), %.

Table 4 shows the components of the slag forming materials used since the beginning of the electric arc process [4].

Table 4. Chemical composition of slag-forming materials, % [4].

Compomemt	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	CO_2	H_2O	S
Iron ore	0.10	0.30	6.25	2.50	90.00	0.15	-	0.70	-
Lime	92.00	3.30	2.50	1.00	0.60	0.10	0.20	0.20	0.10
Dinas - vault	0.60	-	97.00	0.75	1.30	0.75	-	-	-
Magnesite - floor and walls	3.50	90.25	3.45	0.80	2.00	-	-	-	-
Ash - electrodes	11.80	-	56.50	31.70	-	-	-	-	-

According to [4] 2.5 kg per 100 kg charge enters the slag from the walls and floor of the furnace. The magnesite for the oxidation period is $m_{oxid.}^{magnesite\text{-}slag} = 1.0$ kg [4]. The remaining oxides from the walls and floor passing into the slag ($m_{RxOy\text{-}oxid.}^{magnesite\text{-}slag}$) during the oxidation period are:

$$m_{RxOy-oxid.}^{magnesite-slag} = m_{oxid.}^{magnesite-slag}\frac{\%RxOy^{magnesite}}{100}, \text{ kg}, \quad (55)$$

where: RxOy - CaO, SiO_2, Al_2O_3 and Fe_2O_3 in the walls and floor (Table 4), %.

According to [4] 1.2 kg per 100 kg charge is supplied from the dinas vault to the slag. The dinas for the oxidation period is $m_{oxid.}^{dinas\text{-}slag} = 0.2$ kg [4]. The remaining oxides from the vault passing into the slag ($m_{RxOy\text{-}oxid.}^{dinas\text{-}slag}$) during the oxidation period is calculated by:

$$m_{RxOy-oxid.}^{dinas-slag} = m_{oxid.}^{dinas-slag}\frac{\%RxOy^{dinas}}{100}, \text{ kg} \quad (56)$$

where: RxOy - SiO_2, Al_2O_3, Fe_2O_3 and P_2O_5 in the dinas vault (Table 4), %.

During the arc process, it is assumed that the electrodes are consumed in the amount of $m_{EAP}^{electrodes} = 7$ kg per 1 ton of steel or 0.7 kg per 100 kg charge [4]. 20 % of this amount is used for the oxidation period or:

$$m_{oxid.}^{electrodes} = m_{EAP}^{electrodes}\frac{20}{100} = 0.14 \text{ kg / 100 kg charge.} \quad (57)$$

1 % of this quantity of electrodes is ash ($\%electrodes^{ash}$) which enters the slag. Then, the amount of ash from the electrodes passing into the slag ($m_{oxid.}^{electrodes\text{-}ash\text{-}slag}$) will be:

$$m_{oxid.}^{electrodes-ash-slag} = m_{oxid.}^{electrodes}\frac{\%electrodes^{ash}}{100} \text{ kg} \quad (58)$$

The amount of oxides from the ash of the electrodes passing into the slag ($m_{RxOy\text{-}oxid.}^{electrodes\text{-}ash\text{-}slag}$) during the oxidation period is calculated by:

$$m_{RxOy-oxid.}^{electrodes-ash-slag} = m_{oxid.}^{electrodes-ash-slag}\frac{\%RxOy(electrodes)^{ash}}{100}, \text{ kg} \quad (59)$$

where: $\%RxOy^{electrodes\text{-}ash}$ - percentage of participation of the corresponding oxide in the ash from the electrodes (Table 4), %.

Metal composition at the end of the oxidation period [1 - 3, 9]

The elements in the composition of the metal are determined by the following expressions and dependencies:

C: $m_{oxid.\text{-}end}^{[C]} + m_{oxid.}^{SiMn\text{-}[R]}$; Si: $m_{oxid.\text{-}end}^{[Si]} + m_{oxid.}^{SiMn\text{-}[R]}$; Mn: $m_{oxid.\text{-}end}^{[Mn]} + m_{oxid.}^{SiMn\text{-}[R]}$; P: $m_{oxid.\text{-}end}^{[P]} + m_{oxid.}^{SiMn\text{-}[R]}$; S: $m_{oxid.\text{-}end}^{[S]} + m_{oxid.}^{SiMn\text{-}[R]}$,

where: R - respectively, C, Si, Mn, P, S;

Fe in the end of melting (Table 4 of [4]): $m_{Fe}^{melt.\text{-}end}$; Fe, reduced by FeO upon oxidation of the elements C, Si, Mn, P: $m_{Fe}^{oxid.\text{-}C,Si,Mn,P}$, where:

$$m_{Fe}^{oxid.-C,Si,Mn,P} = m_{FeO}^{oxid.-C,Si,Mn,P}\frac{M_{Fe}}{M_{FeO}}, \text{ kg} \quad (60)$$

where: M_{Fe} - molecular mass of Fe; M_{FeO} - molecular mass of FeO; Fe for the formation of FeO by the reaction $Fe_2O_3 + Fe = 3FeO$: $Fe_{oxid.}^{total}$ (is deducted from the amount $m_{Fe}^{melt.\text{-}end} + m_{oxid.}^{SiMn\text{-}[R]} + m_{Fe}^{oxid.\text{-}C,Si,Mn,P}$); FeO:

$$(m_{Fe}^{melt.-end} + m_{oxid.}^{SiMn-[R]} + m_{Fe}^{oxid.-C,Si,Mn,P}) \cdot \frac{\%[FeO]_{oxid.}^{TD}}{100} \quad (61)$$

Amount of gases during oxidation period [1 - 3, 9]

Oxidation of carbon from the metal produces carbon monoxide in an amount calculated by the formula:

$$m_{melt.-end}^{\{CO\}} = m_{oxid.-end}^{\{C\}}\frac{M_{CO}}{A_C}, \text{ kg} \quad (62)$$

where: $m_{melt.\text{-}end}^{\{CO\}}$ - amount of carbon dioxide released during metal oxidation, kg; $m_{oxid.\text{-}end}^{\{C\}}$ - amount of carbon that is oxidized by the end of the oxidation period, such as:

$$m_{oxid.-end}^{\{C\}} = m_R^{r.m.-metal} - \left(m_R^{r.m.-metal}\frac{\%[C]_{oxid.-end}}{100}\right), \text{ kg} \quad (63)$$

where: $m_R^{r.m.\text{-}metal}$ - total amount of non-oxidized element in the metal, with respect to carbon, from the charge materials (Table 4 of [4]), kg; $m_{melt.}^{metal}$ - amount of metal at the end of the melting period (Table 4 of [4]), kg; $\%[C]_{oxid.\text{-}end}$ - percentage of carbon participation in the metal at the end of the oxidation period (assumed to be 0.80 %, which ensures normal degassing of the metal), %; M_{CO} - molecular weight of carbon monoxide; A_C - atomic mass of carbon.

During the oxidation period (unlike the melting period), electrode waste does not participate in the formation of carbon monoxide and carbon dioxide, and the accompanying oxygen, nitrogen and air, which is reflected below in formulas (64) to (74).

70 % of the carbon that will burn from the furnace electrodes and form carbon monoxide will be denoted below by $\%E.\text{-}C \rightarrow CO^{burn}$, and the remaining 30 % of the carbon that will form carbon dioxide will be denoted by $\%E.\text{-}C \rightarrow CO_2^{burn}$.

The electrodes during the oxidation period are consumed in the amount of:

$m_{oxid.}^{electrodes}$ (from [4], 0.14, kg / 100 kg charge) (64)

The carbon needed for carbon oxide is found through:

$$m_{e.}^{C\rightarrow CO} = m_{oxid.}^{electrodes}(\%E. - C \rightarrow CO^{burn})\frac{\%C_{e.}}{100},\ \text{kg} \quad (65)$$

where: $\%C_{e.}$ - percentage of carbon content in the electrodes (according to Table 1 of [4] - 99), %.

CO is calculated using the formula:

$$m_{e.}^{CO} = m_{e.}^{C\rightarrow CO}\frac{M_{CO}}{A_C},\text{kg} \quad (66)$$

The carbon needed for carbon dioxide is found through:

$$m_{e.}^{C\rightarrow CO2} = m_{oxid.}^{electrodes}(\%E. - C \rightarrow CO_2^{burn})\frac{\%C_{e.}}{100}\ \text{kg} \quad (67)$$

CO_2 is calculated using the formula:

$$m_{e.}^{CO2} = m_{e.}^{C\rightarrow CO2}\frac{M_{CO_2}}{A_C},\ \text{kg} \quad (68)$$

Carbon monoxide and carbon dioxide gases are made possible by oxygen from the air, determined by:

$$m_{e.}^{O2\rightarrow CO,CO2} = \{(m_{e.}^{CO} - m_{e.}^{C\rightarrow CO}) + (m_{e.}^{CO2} - m_{e.}^{C\rightarrow CO2})\},\ \text{kg} \quad (69)$$

This oxygen has a volume according to the formula:

$$V_{e.}^{O2\rightarrow CO,CO2} = \{(m_{e.}^{CO} - m_{e.}^{C\rightarrow CO}) + (m_{e.}^{CO2} - m_{e.}^{C\rightarrow CO2})\}\frac{1\ \text{mol}}{MO2}\ \text{m}^3 \quad (70)$$

1mol - one mole of oxygen gas - 22.4; M_{O2} - molecular mass of oxygen.

There is also nitrogen in the air, the mass of which is:

$$m_{e.}^{N2} = \{(m_{e.}^{CO} - m_{e.}^{C\rightarrow CO}) + (m_{e.}^{CO2} - m_{e.}^{C\rightarrow CO2})\}\frac{77}{23},\ \text{kg}, \quad (71)$$

where 77/23 - weight ratio $N_2:O_2$ in the air.

This nitrogen has a volume according to the formula:

$$V_{e.}^{N2} = V_{e.}^{O2\rightarrow CO,CO2}\frac{79}{21},\ \text{m}^3, \quad (72)$$

where 79/21 - volume ratio $N_2:O_2$ in the air.

After adding (70) and (72), the volume of air is obtained:

$$V_{e.}^{air} = V_{e.}^{O2\rightarrow CO,CO2} + V_{e.}^{N2},\ \text{m}^3. \quad (73)$$

Using formulas (69) and (71), we obtain the weight of air:

$$m_{e.}^{air} = m_{e.}^{O2\rightarrow CO,CO2} + m_{e.}^{N2},\text{kg} \quad (74)$$

Carbon dioxide from the decomposition of the lime also passes into the gas phase:

$$m_{lime}^{CO2-gas} = m_{oxid.}^{lime-slag}\frac{\%CO2^{lime}}{100},\text{kg} \quad (75)$$

where $\%CO_2^{lime}$ - carbon dioxide content in the slag-forming material (from [4], Table 2 - 0.20), %.

Water is present in the slag-forming material, which under the conditions of the oxidation period passes as water vapor to the gas phase. Its mass is:

$$m_{lime-oxid.}^{H2O-gas} = m_{oxid.}^{lime-slag}\frac{\%H2O^{lime}}{100},\ \text{kg}, \quad (76)$$

where $\%H_2O^{lime}$ - water content in the slag-forming material (from [4], Table 2 - 0.20), %.

H_2O is also released from the iron ore when heated ($m_{ore}^{H2O\text{-}gas}$), which is calculated by the formula:

$$m_{ore}^{H2O-gas} = m_{ore}^{oxid.}\frac{\%H2O^{ore}}{100},\ \text{kg}, \quad (77)$$

where $\%H_2O^{ore}$ - percentage of moisture participation in the iron ore (from [4], Table 2 - 0.70), %.

The mass of water from the air, passing into the gas phase, is calculated by the expression:

$$m_{air\text{-}oxid.}^{H2O\text{-}gas} = m_{air\text{-}1m3}^{H2O}V_{air\text{-}oxid.},\ \text{kg} \quad (78)$$

where $m_{air\text{-}1m3}^{H2O}$ - quantity of water in 1 m^3 of air (0.012, [1, 4]), kg; $V_{air\text{-}oxid.}$ - quantity of water in the air at 20°C, 760 mm Hg and humidity 70 %, m^3.

The determination of $V_{air\text{-}oxid.}$ is similar to this quantity according to formula (25) from [4].

During the oxidation period, the mass of water from the air will be:

$$m_{oxide}^{H2O} = m_{lime\text{-}oxide}^{H2O\text{-}gas} + m_{ore}^{H2O\text{-}gas} + m_{air\text{-}oxide}^{H2O\text{-}gas},$$

kg. (79)

This water will be reduced by carbon monoxide, releasing hydrogen:

$$m_{oxid.-H2O}^{H2} = m_{oxid.}^{H2O} \frac{M_{H_2}}{M_{H_2O}}, \text{ kg.} \quad (80)$$

This reaction will require carbon monoxide, the mass of which is:

$$m_{oxid.-H2O}^{CO} = m_{oxid.}^{H2O} \frac{M_{CO}}{M_{H_2O}}, \text{ kg.} \quad (81)$$

Carbon dioxide will also be released:

$$m_{oxid.-H2O}^{CO2} = m_{oxid.-H2O}^{CO} \frac{M_{CO_2}}{M_{CO}}, \text{ kg.} \quad (82)$$

RESULTS AND DISCUSSION

When calculating the mathematical formulas from the created model for the oxidation stage, the products obtained are presented below. The data obtained are fundamental for the final, reduction, stage in obtaining bearing steel.

In accordance with the indicated dependencies, the composition and amount of slag from the oxidation period are shown in Table 5.

After an oxidation period, 95 % of the 8.402 kg slag is removed.

The composition of the metal at the end of the oxidation period is calculated and shown in Table 6.

The components of the gas phase from the oxidation period are presented in Table 7.

On this basis, the material balance of the oxidation period shown in Table 8 was calculated.

The calculated data from Table 8 for the oxidation period can be considered normal, according to the batch from the melting period and the materials imported during the current period. Of essential importance in creating the material balance are certain assumptions that are established in the technology of steel production in

Table 6. Composition of the metal at the end of the oxidation period.

	kg	%
C	0.779	0.794
Si	0.047	0.048
Mn	0.291	0.297
P	0.014	0.014
S	0.020	0.020
Fe in the end of melting (Table 1)	95.263	
Fe from SiMn	0.035	
Fe, reduced by FeO upon oxidation of the elements C, Si, Mn, P	2.640	
Fe for the formation of FeO by the reaction $Fe_2O_3 + Fe = 3FeO$ (is deducted from the amount $m_{Fe}^{melt.-end} + m_{oxid.}^{SiMn-[R]} + m_{Fe}^{oxid.-C,Si,Mn,P}$)	-1.062	
Total Fe	96.876	98.702
FeO	0.123	0.125
Total steel	98.150	100.000

Table 5. Mass and composition of slag from the oxidation period.

	Source of income, kg							Total	
oxide	from slag-melting	from metal	from iron ore	from lime	from floor and walls	from vault	from ash - electrod	kg	%
CaO	0.841	-	0.004	3.280	0.035	0.001	0.0002	4.161	49.52
MgO	0.300	-	0.011	0.118	0.903	-	-	1.332	15.85
SiO_2	0.346	0.190	0.236	0.089	0.034	0.194	0.0008	1.092	13.00
Al_2O_3	0.014	-	0.094	0.036	0.008	0.001	0.0005	0.154	1.83
FeO	0.090	-	0.660	-	-	-	-	0.750	8.93
Fe_2O_3	0.039	-	0.339	0.021	0.020	0.003	-	0.422	5.02
MnO	0.133	0.284	-	-	-	-	-	0.410	4.88
P_2O_5	0.008	0.043	0.006	0.004	-	0.001	-	0.062	0.74
S	-	0.01	-	0.004	-	-	-	0.014	0.17
Total	1.771	0.527	1.350	3.552	1.000	0.200	0.002	8.402	100.0

Table 7. Gas phase from the oxidation period.

Gas	kg	%
Carbon oxide	1.282	54.32
Carbon dioxide	0.266	11.27
Nitrogen	0.807	34.20
Hydrogen	0.005	0.21
Total	2.360	100

Table 8. Material balance of the oxidating period.

Expenditure	kg	Income	kg
Metal (from melting period)	96.960	Metal	98.150
Slag (from melting period)	1.771	Slag	8.402
Silicomanganese	0.250	Gas	2.360
Iron ore	3.773		
Lime	3.570		
Electrodes	0.140		
Magnesite	1.000		
Dinas	0.200		
Air	1.048		
Unattached	0.200		
Total	108.912		108.912

an electric furnace. For the liquid metal after the melting period, it is assumed that during the oxidation period there are no losses in the gas phase. The amount of dinas and magnesite refractories that pass to the slag in the balance is of intermediate values. The same applies to the amount of substance burned from the electrodes during this process. The slag presented in the consumption part represents 30 % of the slag obtained during the melting period. The remaining 70 % of it is removed before the beginning of the oxidation period. About 95 % of the presented amount of slag in the revenue part is removed at the end of the oxidation period. Thus, for the next period - reduction, about 5 % of this slag remains.

CONCLUSIONS

- The development has made a material balance for the oxidation stage, concerning electric furnace processing of the charge to produce specific steel.
- All presented dependencies are consistent with the technological sequence for conducting this stage. The numerical data in Tables 5, 6, 7 and 8 are calculated based on the current model, as well as the information from the first stage - melting, presented in a previous issue of the journal.
- Through this material balance, the values for the gas, slag and metal product can be quickly reached, for any change in the previous stage of steelmaking.

Authors' contributions: All studies described in the manuscript are prepared by P.P.

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