Distribution of manganese and silicon between metal and slag in the processes of high-temperature processing of natural ores into ferrous metals

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Experimental studies have been carried out on the equilibrium distribution of manganese and silicon between pig iron, foundry cast iron, carbon ferromanganese and slags at the temperatures 1450, 1500, 1550 °C in a CO atmosphere. Using the found equilibrium concentrations of condensed phases, the distribution coefficients of manganese and silicon between the metal and the slag were calculated. It has been established that the distribution coefficient of manganese is significantly higher in experiments with ferromanganese than in experiments with cast iron, and the indicator for foundry cast iron is higher than that for pig iron. Relationships between the equilibrium distribution of the elements and the slag composition were established. To characterize the latter, optical basicity was used, which was determined through the electric negativity and electron density of the elements of the Periodic Table. The empirical equations that describe the dependence of distribution coefficients on the optical basicity of the slag were obtained by mathematical processing of experimental results. It turned out that this dependence is described by an equation with a high correlation coefficient ($R = 0.93$), and for manganese - with a low one ($R = 0.65$) for the case of silicon reduction. Analysis of the influencing factors revealed the need to take into account the influence of silicon in the latter case. The equation obtained in this case describes the dependence of the distribution coefficient with a correlation coefficient $R = 0.98$. This means that it is necessary to take into account the occurrence of the exchange reaction $2(MnO) + [Si] = SiO_2 + 2[Mn]$, which is a combination of the other two reactions of manganese $(MnO) + C = [Mn] + CO$ and silicon $(SiO_2) + 2C = [Si] + 2CO$, during the carbothermal processing of ores containing manganese and silicon oxides, in addition to the two above-mentioned reactions. The practical result of the work is the possibility of assessing the distribution of manganese and silicon for slags of any composition due to the use of the optical basicity indicator, calculated from the electric negativity and electron density known for all elements.

Key words: metal, slag, pig iron, foundry cast iron, manganese, silicon, equilibrium distribution, carbothermal processing.

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Introduction

Manganese and silicon are the permanent components of foundry cast iron and pig iron, steel and several manganese ferroalloys. While quartzite reserves are sufficient to manufacture silicon alloys, only limited number of countries has reserves of manganese ores. From the other side, a through coefficient of manganese extraction in metal does not exceed 50 % and its lack for production of metals should not be reported. The present achievements in production of manganese ferroalloys can't be identified as high ones, because manganese content in dump slags can make up to 20 %. To overcome this appearance, many countries carried out large-scale theoretical and applied researches [1–8]. The researches for establishing the conditions of maximal transition of the leading element in metal are considered as most valuable. They are revealed during conduction of equilibrium experiments. Such studies were undertaken earlier, but they were carried out either within narrow temperature range [9], or they were based on the data of production practice [2, 3], where achievement of equilibrium can't be guaranteed. In this connection, equilibrium distribution of manganese and silicon during interaction of cabon-saturated alloys and silicate slags of the system $CaO–SiO_2–Al_2O_3–MgO–MnO$ was examined experimentally in this research.

Methods of the research

The experiments on studying distribution of the elements between metal and slag are carried out according to the technique [10, 11], which allows to assess equilibrium at each preset partial pressure of carbon monoxide and provides possibility of quick process realization for "oxidation-reduction" interface. The fact of equilibrium achievement was recorded via varying of CO amount (as a result of course of reactions) and chemical analysis of condensed phases. Composition of gaseous reaction products during experiments was continuously controlled by an optical acoustic analyzer. To rise precision of equilibrium temperature reporting, it was realized both from the positions of reduction and oxidation of the elements via varying CO amount which is transferred to a reaction area in the conditions of its permanent pressure. To exclude varying of metal and slag composition under effect of external factors, a reaction crucible was fabricated of gas-dense molybdenum. Metal and slag for experiments were prepared of high purity reactants via multiple remelting and averaging in a protective atmosphere.

Research results and their analysis

According to the approved technique for equilibrium examination with CO gaseous phase participation in the experiments for manganese and silicon distribution between metal and slag, the following two parallel reactions were studied:

$$(\mathrm{MnO}) + \mathrm{C} = [\mathrm{Mn}] + \mathrm{CO}: \tag{1}$$

$$\mathrm{K_{Mn}} = \frac{a_{[\mathrm{Mn}]} \cdot P_{\mathrm{CO}}}{a_{(\mathrm{MnO})} \cdot a_{[C]}} = \frac{N_{[\mathrm{Mn}]} \cdot \gamma_{[\mathrm{Mn}]} \cdot P_{\mathrm{CO}}}{N_{(\mathrm{MnO})} \cdot \gamma_{(\mathrm{MnO})} \cdot a_{[C]}} = L_{\mathrm{Mn}} \cdot \frac{\gamma_{[\mathrm{Mn}]}}{\gamma_{(\mathrm{MnO})}} \cdot \frac{P_{\mathrm{CO}}}{a_{[C]}} \tag{2}$$

$$(\mathrm{SiO_2}) + 2\mathrm{C} = [\mathrm{Si}] + 2\mathrm{CO}; \tag{3}$$

$$\mathrm{K_{Si}} = \frac{a_{[\mathrm{Si}]} \cdot P^{2\mathrm{co}}}{a_{(\mathrm{SiO_2})} \cdot a^{2[C]}} = \frac{N_{[\mathrm{Si}]} \cdot \gamma_{[\mathrm{Si}]} \cdot P^{2\mathrm{co}}}{N_{(\mathrm{SiO_2})} \cdot \gamma_{(\mathrm{SiO_2})} \cdot a^{2[C]}} = L_{\mathrm{Si}} \cdot \frac{\gamma_{[\mathrm{Si}]}}{\gamma_{(\mathrm{SiO_2})}} \cdot \frac{P^{2\mathrm{co}}}{a^{2[C]}} \tag{4}$$

Additionally, the real exchange reaction between metal and slag was examined, taking into account methodical features of conducting of equilibrium eaperiments in the conditions of permanent partial pressure of carbon dioxide with carbon excess:

$$2(\mathrm{MnO}) + [\mathrm{Si}] = \mathrm{SiO_2} + 2[\mathrm{Mn}]. \tag{5}$$

This reaction is a thermodynamic result of subtraction of the third reaction from the first one. The equilibrium constant of this reaction looks like

$$\mathrm{K_{MnSi}} = \frac{\mathrm{a}^2{}_{[\mathrm{Mn}]} \cdot \mathrm{a}_{(\mathrm{SiO_2})}}{\mathrm{a}^2{}_{(\mathrm{MnO})} \cdot \mathrm{a}_{[\mathrm{Si}]}} = \frac{\mathrm{N}^2{}_{[\mathrm{Mn}]} \cdot \gamma^2{}_{[\mathrm{Mn}]} \cdot \mathrm{N}_{(\mathrm{SiO_2})} \cdot \gamma_{(\mathrm{SiO_2})}}{\mathrm{N}^2{}_{(\mathrm{MnO_2})} \cdot \gamma^2{}_{(\mathrm{MnO})} \cdot \mathrm{N}_{[\mathrm{Si}]} \cdot \gamma_{[\mathrm{Si}]}} = \frac{\mathrm{L}^2{}_{\mathrm{Mn}}}{\mathrm{L_{Si}}} \cdot \frac{\gamma^2{}_{[\mathrm{Mn}]} \cdot \gamma_{(\mathrm{SiO_2})}}{\gamma^2{}_{(\mathrm{MnO})} \cdot \gamma_{[\mathrm{Si}]}}. \tag{6}$$

According to the experimental conditions, $\mathrm{P_{CO}} = 1$ atm., while $\mathrm{a_{[C]}} = 1$. The coefficients of manganese and silicon distribution as well as their relations can be presented in this case in such way:

$$\mathrm{L_{Mn}} = \frac{[\mathrm{Mn}]}{(\mathrm{MnO})} = K_{\mathrm{Mn}} \cdot \frac{\gamma_{(\mathrm{MnO})}}{\gamma_{[\mathrm{Mn}]}} \cdot a_1 \tag{7}$$

$$\mathrm{L_{Si}} = \frac{[\mathrm{Si}]}{(\mathrm{SiO_2})} = K_{\mathrm{Si}} \cdot \frac{\gamma_{(\mathrm{SiO_2})}}{\gamma_{[\mathrm{Si}]}} \cdot a_2 \tag{8}$$

$$\frac{\mathrm{L^2_{Mn}}}{\mathrm{L_{Si}}} = \frac{[\mathrm{Mn}]^2 \cdot (\mathrm{SiO_2})}{(\mathrm{MnO})^2 \cdot [\mathrm{Si}]} = \mathrm{K_{MnSi}} \cdot \frac{\gamma^2{}_{(\mathrm{MnO})} \cdot \gamma_{[\mathrm{Si}]}}{\gamma^2{}_{[\mathrm{Mn}]} \cdot \gamma_{(\mathrm{SiO_2})}} \cdot \mathrm{a}_3. \tag{9}$$

where: $\mathrm{a_1, a_2, a_3}$ — transition coefficients of molar component concentrations in weight percents.

Compositions of metals and slags classified by equilibrium distribution of the elements after conduction of the experiments are presented in the **Table 1** and **Table 2**. Used pig iron and foundry cast iron (the experiments 1–19 and 17–24 respectively) are shown in the Table 1, while Table 2 displays the data of 11 experiments as an example (from total 29 experiments with carbonaceous ferromanganese.

To establish the links between equilibrium content of the elements and slag composition, the term of optical basicity was used. This appearance was widely distributed owing to itd link with electric negativity, e.g. Poling electric negativity χ [12]:

$$\lambda_\mathrm{i} = 1 / 1.36\ (\chi - 0.26). \tag{10}$$

For a complicated system:

$$\lambda = \Sigma\lambda_\mathrm{i}\mathrm{X_i},. \tag{11}$$

where: λ_I — basicity of the system component; $\mathrm{X_i}$ — equivalent part of anions, which were introduced by this component, e.g. for CaO–$\mathrm{A1_2O_3}$–$\mathrm{SiO_2}$:

$$\mathrm{X_{CaO} = N_{CaO} / (N_{CaO} + 3N_{Al_2O_3} + 2N_{SiO_2}) = N_{CaO} / \Sigma N_o}. \tag{12}$$

$$\mathrm{X_{Al_2O_3} = 3N_{Al_2O_3} / \Sigma N_o}. \qquad \mathrm{X_{SiO_2} = 2N_{SiO_2} / \Sigma N_o}. \tag{13}$$

When slag are characterized by the elements with variable valence, we can use the results of development, which establish its link with electronic density (Di), for calculation of optical basicity [13]:

$$\lambda_\mathrm{i} = 1 / 1.34\ (\mathrm{D_i} + 0.6). \tag{14}$$

This expression provides the results that practically coincide with the equation (10) for the main slag components (CaO, $\mathrm{SiO_2}$, $\mathrm{Al_2O_3}$). The values of optical basicity for several compounds, taking from the technical literature, are presented in the **Table 3**.

It should be underlined that possibility of taking into account all components containing in slag is the important advantage of the suggested indicator. Optical basicity does not restrict the number of considered slag melt components and is a good reflection of physical essence of the processes occurring in a furnace space.

The equations for determination of optical basicity for multi-component slag melts were concluded by the authors in order to simplify practical calculations. They were found out based on the known values of optical basicity of individual oxides (see Table 3), taking into account the values

$$\lambda_\mathrm{D} = \frac{0.0179(\mathrm{CaO}) + 0.016(\mathrm{SiO_2}) + 0.0178(\mathrm{Al_2O_3}) + {}}{0.0179(\mathrm{CaO}) + 0.0333(\mathrm{SiO_2}) + 0.0294(\mathrm{Al_2O_3}) + {}} \frac{+0.0195(\mathrm{MgO}) + 0.0083(\mathrm{MnO}) + 0.0071(\mathrm{FeO}) + 0.018(\mathrm{B_2O_3}) + {}}{+0.025(\mathrm{MgO}) + 0.0141(\mathrm{MnO}) + 0.0139(\mathrm{FeO}) + 0.0429(\mathrm{B_2O_3}) + {}} \frac{+0.0109(\mathrm{Cr_2O_3}) + 0.0153(\mathrm{TiO_2}) + 0.0075(\mathrm{BaO})}{+0.0197(\mathrm{Cr_2O_3}) + 0.025(\mathrm{TiO_2}) + 0.0065(\mathrm{BaO})} \tag{15}$$

$$\lambda_\mathrm{ED} = \frac{0.0179(\mathrm{CaO}) + 0.0157(\mathrm{SiO_2}) + 0.0194(\mathrm{Al_2O_3}) + {}}{0.0179(\mathrm{CaO}) + 0.0333(\mathrm{SiO_2}) + 0.0294(\mathrm{Al_2O_3}) + {}} \frac{+0.023(\mathrm{MgO}) + 0.0134(\mathrm{MnO}) + 0.0131(\mathrm{FeO}) + 0.018(\mathrm{B_2O_3}) + {}}{+0.025(\mathrm{MgO}) + 0.0141(\mathrm{MnO}) + 0.0139(\mathrm{FeO}) + 0.0429(\mathrm{B_2O_3}) + {}} \frac{+0.0152(\mathrm{Cr_2O_3}) + 0.0162(\mathrm{TiO_2}) + 0.0071(\mathrm{BaO})}{+0.0197(\mathrm{Cr_2O_3}) + 0.025(\mathrm{TiO_2}) + 0.0065(\mathrm{BaO})} \tag{16}$$

Table 1. Chemical composition of cast iron and slag

No. of experiment	Metal composition, % (mass.)			Slag composition, % (mass.)				
	Mn	Si	C	CaO	SiO_2	Al_2O_3	MgO	MnO
Temperature of the experiment 1450 °C								
1	0.75	0.72	4.39	36.32	40.30	15.10	7.07	1.29
2	0.21	0.86	4.31	32.56	37.21	15.60	14.37	0.29
3	0.20	0.76	4.29	41.09	39.03	14.18	5.44	0.25
4	0.32	0.97	4.368	42.64	39.66	12.03	6.15	0.50
5	0.45	0.88	4.60	37.95	37.37	14.20	9.80	0.63
6	0.28	0.38	4.47	40.26	39.68	7.04	12.68	0.34
7	0.27	0.38	4.465	40.34	39.46	7.12	12.70	0.33
8	0.20	0.79	4.37	41.07	38.05	13.20	7.46	0.20
9	0.23	0.83	4.358	40.76	38.00	13.76	7.21	0.22
10	1.08	0.72	4.393	42.62	37.82	12.07	6.46	1.00
11	2.02	0.56	4.03	45.41	37.67	11.10	3.26	2.70
12	1.14	0.75	4.432	48.73	39.71	7.09	3.34	1.10
13	0.82	0.67	4.36	49.31	39.53	6.42	3.87	0.85
14	0.42	0.93	4.27	49.47	39.29	5.75	4.97	0.43
15	0.91	0.67	4.446	48.50	37.21	10.76	2.60	0.91
16	0.61	1.18	4.23	47.63	35.99	10.00	6.89	0.47
Temperature of the experiment 1550 °C								
17	0.27	2.74	3.805	30.58	38.76	15.55	14.83	0.27
18	0.32	2.64	3.892	37.75	41.55	8.19	12.22	0.29
19	0.71	2.44	3.95	44.17	39.65	9.86	5.79	0.52
20	0.58	2.72	3.87	44.08	37.38	10.38	7.90	0.26
21	0.62	2.50	3.99	44.44	36.94	11.08	7.20	0.34
22	0.67	2.77	3.77	47.28	38.74	8.95	4.58	0.45
23	0.59	2.74	4.00	47.72	39.09	7.89	4.90	0.40
24	0.62	2.81	3.86	48.00	37.33	8.89	5.43	0.36

Table 2. Chemical composition of ferromanganese and slag at the experimental temperature 1500 °C

No.	Metal composition, % (mass.)				Slag composition, % (mass.)				
	Mn	Si	Fe	C	MnO	SiO_2	CaO	Al_2O_3	MgO
1	73.92	1.88	14.50	6.68	17.75	38.53	34.06	3.88	5.81
2	77.20	0.19	14.50	6.70	14.15	31.22	27.25	14.74	9.25
3	76.76	0.20	14.50	7.34	13.90	33.28	32.70	9.88	8.17
4	77.42	0.36	14.75	7.12	10.67	32.18	35.20	14.42	5.70
5	76.98	0.14	14.25	7.68	10.98	30.16	34.50	13.765	7.31
6	76.54	0.06	14.50	7.74	12.16	27.32	33.61	14.66	9.25
7	77.64	0.12	14.25	7.16	9.80	29.66	39.96	12.23	9.46
8	77.42	0.07	14.25	7.70	14.27	25.83	35.88	15.93	6.67
9	77.64	0.06	14.74	7.44	10.30	31.22	49.05	7.50	4.73
10	74.04	1.33	14.22	7.53	17.67	37.80	33.36	4.05	3.94
11	76.36	0.05	14.38	7.78	14.98	24.09	32.90	15.36	5.71

of anion charge, number of anions in a concrete component and its molar concentration.

The expressions of optical basicity (Poling – λ_D, electronic density – λ_{ED}) for slag melts, which include e.g. up to 10 components in their composition, were obtained:

Computer program for calculation of optical basicity, allowing to reveal basicity of slag melts or fluxes with any combination of the components of oxides, chlorides and fluorides in correspondence with the data of the Table 3, was created using the presented models.

The selected data of experimental researches of manganese and silicon equilibrium distribution between condensed phases at the temperatures 1450, 1500 and 1550 °C are displayed in the Table 4; these phases are partially graphically illustrated in the **Fig. 1**. It can be seen that indicators of manganese distribution rise for all kinds of manganese-containing alloys (cast iron and ferroalloys) as soon as slag basicity increases. In this case the coefficient of manganese distribution is essentially higher in the experiments with ferromanganese that in experiments with cast iron, while foundry cast iron indicator is higher in comparison with pig iron indicator. It can be explained mainly by significant variation of manganese activity coefficient in the alloy during transition from cast iron to ferroalloy (in the conditions of slight temperature

Table 3. Optical basicity of compounds, based on electronic density (λ_{EDi}) and Poling electric negativity ((λ_{Di})

Component	Optical basicity		Component	Optical basicity		Component	Optical basicity		Component	Optical basicity	
	λ_{EDi}	λ_{Di}		λ_{EDi}	λ_{Di}		λ_{EDi}	λ_{Di}		λ_{EDi}	λ_{Di}
Li_2O	1.06	1.00	MnO	0.95	0.59	Cr_2O_3	0.77	0.55	CaF_2	0.67	0.67
Na_2O	1.11	1.15	FeO	0.94	0.51	As_2O_3	0.72	0.42	S_2F_2	0.72	–
K_2O	1.16	1.36	Fe_2O_3	0.72	0.48	Sb_2O_3	0.84	0.45	BaF_2	0.78	–
Rb_2O	1.17	1.36	CoO	0.93	0.45	Bi_2O_3	0.92	0.45	$MgCl_2$	0.62	–
Cs_2O	1.18	1.67	NiO	0.92	0.45	SiO_2	0.48	0.47	$CaCl_2$	0.72	–
MgO	0.92	0.78	ZnO	0.91	0.55	GeO_2	0.58	0.48	S_2Cl_2	0.79	–
CaO	1.00	1.00	CuO	0.89	0.45	TiO_2	0.65	0.61	$BaCl_2$	0.84	–
S_2O	1.04	0.33	B_2O_3	0.42	0.42	P_2O_5	0.38	0.40	NaF	0.67	–
BaO	1.08	1.15	Al_2O_3	0.66	0.61	MgF_2	0.51	–	NaCl	0.68	–

Table 4. The data of manganese and silicon equilibrium distribution between metal and slag

No.	Slag basicity		$\frac{[Mn]}{(MnO)}$	$\frac{[Si]}{(SiO_2)}$	$\frac{[Mn]^2}{(MnO)^2} \cdot \frac{(SiO_2)}{[Si]}$
	$\frac{CaO}{SiO_2}$	λ			
Temperature t = 1450 °C (cast iron)					
1	0.9	0.6672	0.58	0.0179	18.79
2	0.88	0.6823	1.04	0.0231	46.82
3	1.05	0.676	0.77	0.0195	30.41
4	1.05	0.6802	0.64	0.0245	16.72
5	1.01	0.6841	0.71	0.0235	21.45
6	1.015	0.691	0.83	0.0096	71.76
7	1.02	0.6919	0.62	0.0096	40.04
8	1.08	0.6834	1.0	0.0208	48.08
9	1.07	0.6822	1.04	0.0218	49.61
10	1.13	0.6866	1.08	0.0190	61.39
11	1.20	0.6887	0.75	0.0149	37.75
12	1.23	0.6894	1.04	0.0189	57.23
13	1.25	0.6923	0.96	0.0169	54.53
14	1.26	0.6955	0.98	0.0237	40.52
15	1.30	0.6928	1.0	0.018	55.56
16	1.32	0.7038	1.3	0.0328	51.52
Temperature t = 1500 °C (ferromanganese)					
17	0.88	0.6925	4.16	0.0488	355.4
18	0.87	0.6969	5.46	0.0061	4891.0
19	0.98	0.7021	5.52	0.0060	5074.5
20	1.09	0.6985	7.26	0.0112	4706.2
21	1.14	0.7079	7.01	0.0046	10588.9
22	1.23	0.722	6.29	0.0022	18040.1
23	1.35	0.7252	7.92	0.0040	15513.3
24	1.39	0.7276	5.43	0.0027	10861.5
25	1.57	0.734	7.54	0.0019	29565.3
26	0.88	0.6874	4.19	0.0352	499.0
27	1.37	0.7271	5.10	0.0021	12519.3
Temperature t = 1550 °C (cast iron)					
28	0.80	0.6751	1.0	0.0707	14.14
29	0.91	0.679	1.1	0.0635	19.06
30	1.11	0.6834	1.37	0.0615	30.52
31	1.18	0.6938	2.22	0.0728	67.70
32	1.20	0.6942	1.82	0.0677	48.93
33	1.22	0.6902	1.49	0.0715	31.05
34	1.22	0.6912	1.47	0.0701	30.83
35	1.29	0.6977	1.72	0.0753	39.29

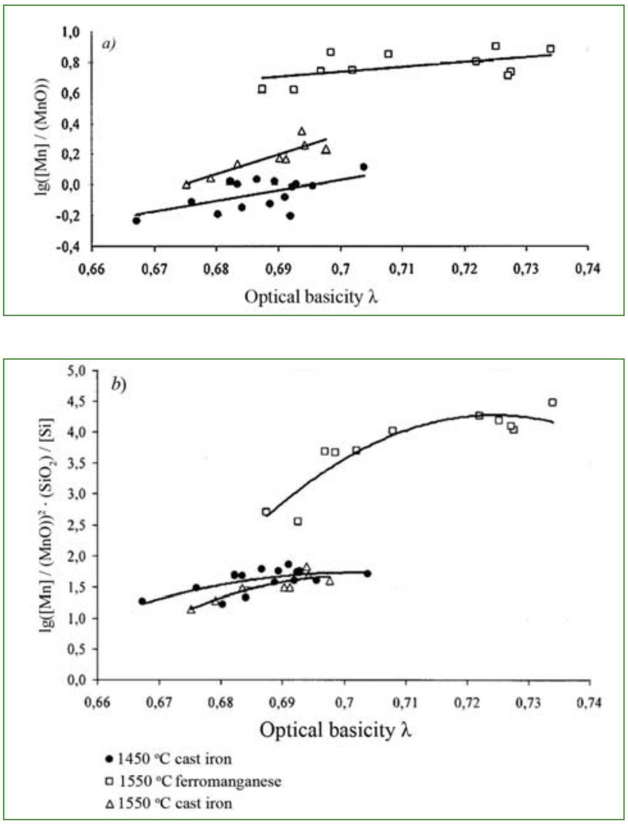

Fig. 1. Influence of slag basicity on manganese distribution coefficients with (*a*) and without (*b*) silicon accounting

fluctuations). It can be apparently seen from the equation (7), meaning that there is no substantial difference in MnO activity coefficients for the same slag basicity.

The empiric equations describing relationships between distribution coefficients and slag optical basicity are obtained via mathematical processing of the experimental results. The data of chemical analysis of metal and slag were used in this case. E.g., the following relationships were found out for equilibrium experiments with ferromanganese at the temperature 1500 °C:

$$\lg\frac{[\mathrm{Si}]}{(\mathrm{SiO_2})} = 791.5\cdot\lambda^2 - 1151.2\cdot\lambda + 416.0 \qquad \mathrm{R} = 0{,}93 \qquad (17)$$

$$\lg\frac{[\mathrm{Mn}]}{(\mathrm{MnO})} = -205.5\cdot\lambda^2 + 295.4\cdot\lambda - 105.3 \qquad \mathrm{R} = 0{,}65 \qquad (18)$$

$$\lg\frac{[\mathrm{Mn}]^2\cdot(\mathrm{SiO^2})}{(\mathrm{MnO})^2\cdot[\mathrm{Si}]} = -1203.2\cdot\lambda^2 + 1743\cdot\lambda - 625.9 \qquad \mathrm{R} = 0{,}92 \qquad (19)$$

Rather high coefficient of pair correlation in the equations (17) and (19) and rather low coefficient of manganese distribution in the equation (18) attract the attention. It testifies on the fact that varying of manganese distribution occurs not only under the effect of slag basicity, but also from the other factor – silicon content in the metal.

In this connection, varying of manganese distribution according to the equations (7) and (9) was examined depending on joint influence of silicon concentration in the metal and optical slag basicity in the form of multiple linear correlation. E.g. the developed regression equations for the same experimental conditions (1500 °C, ferromanganese) look like:

$$\lg\frac{[\mathrm{Mn}]}{(\mathrm{MnO})} = -0.07\cdot[\mathrm{Si}] + 2.3\cdot\lambda - 0.74 \qquad \mathrm{R} = 0.78 \qquad (20)$$

$$\lg\frac{[\mathrm{Mn}]^2\cdot(\mathrm{SiO_2})}{(\mathrm{MnO})^2\cdot[\mathrm{Si}]} = -0{,}68\cdot[\mathrm{Si}] + 14.58\cdot\lambda - 6.33 \qquad \mathrm{R} = 0.98 \qquad (21)$$

We have to wait that the coefficients of multiple correlation are essentially higher than such pair relationships. High tightness of mutual correlation (equation (21), R = 0.98) between silicon content in the metal, slag basicity and expression

$$\frac{[\mathrm{Mn}]^2}{(\mathrm{MnO})^2}\cdot\frac{(\mathrm{SiO_2})}{[\mathrm{Si}]}$$

should be especially noted. The last indicator is like equilibrium constant of the reaction 2(MnO) + [Si] = 2[Mn] + + (SiO_2) (5) in its structure, but it can't classified as this constant because it depends on concentrations of the components taking part in this reaction. This expression is only an equilibrium characteristic and is usually named as "apparent" equilibrium constant.

Based on the established regularity and high degree of interaction between the above-mentioned three parameters, we can suggest that the exchange reaction (5) is a final stage of oxidizing and reducing processes with participation of manganese and silicon.

Conclusion

Experimental studies have been carried out on the equilibrium distribution of manganese and silicon between pig iron, foundry cast iron, carbon ferromanganese and slags at the temperatures 1450, 1500, 1550 °C in a CO atmosphere. The fact of equilibrium achieving was recorded by varying of CO amount as a result of conduction of the reactions and chemical analysis of condensed phases. Composition of gaseous products of the reactions was controlled continuously during experiments via optical-acoustic analyzer. To increase accuracy of the equilibrium temperature, it was managed from the sides of both reduction and oxidation of the elements via varying of CO introducing in the reaction area with its permanent pressure. To establish the link between equilibrium content of the elements in metal and slag composition, the term of optical basicity was used. It was found out that indicators of manganese distribution increase for all types of manganese-containing alloys (cast iron and ferroalloys) as soon as slag basicity rises. In this case, the manganese distribution coefficient in the experiments with ferromanganese is rather higher than that in the experiments with cast iron, while indicator for cast iron is higher than that for pig iron; it is explained by significant variation of manganese activity coefficient in the alloy during transition from cast iron to ferroalloy. Silicon distribution coefficient between metal and slag with rather high correlating properties (R = 0.93) is connected with optical basicity. Similar mathematical link for manganese is characterized by correlation coefficient

R = 0.65. However, additional accounting of silicon presence in the metal allows to increase correlation coefficient up to the level R = 0.98. It means that the exchange reaction $2(MnO) + [Si] = SiO_2 + 2[Mn]$ is a final stage of oxidizing and reducing processes with participation of manganese and silicon.

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