JP&M Engineering

Journal of Petroleum and Mining Engineering

Influence of Slag Composition and Temperature on Silicon Distribution between Slag and Hot Metal in the Egyptian Blast Furnace No.III

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Abstract

Daily average slag and the corresponding hot metal samples were collected on tapping of BF No.III of the Egyptian Iron and Steel Company (EISCO) and analyzed. The temperature of hot metal was measured during metal tapping. The useful volume of the furnace, which was charged with 100% self- fluxing sinter, is $1033m^3$.The analyses of slag and hot metal together with the metal temperature were used to estimate activity coefficient and activity of silica in the slag according to the statistical theory of regular ionic solutions. The silicate capacity of the slag and distribution of silicon between slag and hot metal were also assessed. The change of silicon activity in hot metal with the concentration was also treated. The activity coefficient of silicon was found to be 1.324. Calculated silicon distribution ratios satisfactorily correlate with the relevant values obtained from the chemical analysis. The effect of temperature on both silicate capacity and silicon distribution is very large compared with the influence of the slag basicity. The best correlation results were achieved when the basicity definition contains CaO and its equivalents of basic oxides.

Keywords

Blast Furnace; Silicate Capacity; Slag- Metal Silicon Distribution.

Introduction

The Egyptian Iron and Steel Company (EISCO) has four blast furnaces. Blast furnace (BF) No.I and BF No.II are identical and have a useful volume of 575 m3 each. BF No.III and BF No.IV are also identical and have a useful volume of $1033m^3$ each. The four furnaces operate on self fluxing sinter having a relatively high content of silica (around 8.5wt%, on average).

The main source of silica in the BF feed is the local iron ore charged in form of sinter. Coke ash also contributes to the silica content of the blast furnace stock.

As the charge moves downwards and reaches the high temperature levels inside the furnace, SiO_2 will be reduced to Si which dissolves in the hot metal. The first step in silicon transfer into the metal is the in situ reduction of SiO_2 in the coke ash resulting from coke combustion in front of the furnace tuyeres to gaseous SiO. The reduction process is accomplished by further reaction of SiO in the gas phase with the carbon dissolved in the trickling metal droplets passing through the region extending between the bosh and the hearth and gets transferred as silicon to the metal. The reduction of SiO2 to volatile SiO proceeds also by the action of C in the coke, CO or SiC [1-7].

Hot metal with low silicon content is required for the production of steel in LD converter. The reduction of SiO_2 to Si in blast furnace needs more coke which leads to an increase in the production cost of hot metal and steel [6]. The principles of the theory and practice needed for producing low silicon hot metal are available in literature [8].

Coke reactivity and carbon solution loss play an important role in lowering the silicon content of hot metal. Low reactivity coke and low C solution loss make it easy to produce hot metal with low silicon content [9].

The kinetics of reduction of SiO2 and silicate slag containing SiO2, CaO and Al2O3 to volatile SiO were studied and the rate of formation of SiO was determined [10, 11].

The most important factors affecting silicon distribution between slag and hot metal are temperature and slag basicity [12]. Higher temperature leads to increasing the Si content of hot metal. An increase in the slag basicity, on the other hand, causes a decrease in the activity of SiO_2 in the slag and raises the ratio of Si distribution between slag and metal. The basicity (CaO/SiO_2), of a normal basic BF slag lies in the range between 1.0and1.5 whereas that of an acid slag is between 0.8 and 1.0 [13]. The BF under investigation uses relatively acid slag because of the presence of high MnO contents in the sinter [14].

Experimental Work

The experiments were carried out on BF No.III at EISCO during May to July 2014. The furnace was charged with fluxed sinter and running under normal operational conditions. Daily average slag samples were collected for analysis. The metal samples were collected cast by cast and their analysis was averaged over the whole day. The slag samples were prepared for analysis by grinding and magnetic separation of the metallic iron. They were analyzed by using the normal wet methods. The determination of SiO_2, Al_2O_3 and S was done gravimetrically. Complex metric titration using Eriochrome Black T with Na_2EDTA as indicator was applied for determining the total of $Ca^{++}$and Mg^{++}. Calcium ions were estimated by titration in a separate quantity of the solution using Na_2EDTA in the presence of murexide. FeO was determined by titration against standard $KMnO_4$ solution. MnO was found titrimetrically. The methods of analysis used have an accuracy of ± 0.5% of the analytical results. The contents of C and S in the hot metal samples were determined by using the standard combustion method. Mn and P in the metal were estimated volumetrically. Si, on the other hand, was found gravimetrically.

The temperatures used in the present investigation are those of the hot metal. They are the average of at least 10 readings taken during metal tapping from the furnace.

Results and Discussion

The ranges of daily average slag and hot metal analyses and the corresponding average of hot metal temperatures are given in Table 1. The silicon content of hot metal ranges between 0.22 and 0.69 wt%. In a number of samples provided by EISCO, the silicon content of hot metal reached 1.5% which is higher than the upper limit of optimal silicon concentration in hot metal normally used for steel making in a basic oxygen converter (0.8%) [15]. Large fluctuation of Si in hot metal has negative effects on iron making in BF. It causes an increase in coke consumption and decrease in the iron output of BF. High Si hot metal has also detrimental effects on converter steelmaking because it leads to high flux consumption, high slag volume and decrease in steel yield.

The low bascicty of the slag (CaO/SiO_2= 0.747 to 1.176) is applied to the blast furnace because of the high MnO in the sinter. As above mentioned, basic BF slag has basicity, (CaO/SiO_2), in the range between 1.0 and 1.5 whereas the basicity of acid slag is in the range between 0.8and 1.0[13].

The hot metal and slag analyses used in the present work will be utilized to investigate the effects of slag composition, characterized by the slag basicity, and temperature on the silicon distribution between slag and hot metal. The concept of slag capacity will be used for this purpose. The estimation of silicate capacity requires knowledge of activity coefficient and activity of silica in the slag in addition to activity coefficient and activity of Si in the metal.

Activity coefficient of silica in the slag

The activity coefficient of silica in the slag was determined by using the model of regular ionic solutions[16, 17].

$$ln\,\gamma_{(SiO2)} = \frac{1203}{T}[(1 - x_{(SiO2)}\ (0.92x_{(FeO)} - 4.18x_{(MnO)} - 11.29x_{(CaO)} - 11.29x_{(MgO)} + 12.54x_{(Al2O3)}) + x_{(FeO)}\left(x_{(CaO)} + 2.51x_{(Al2O3)}\right) - x_{(Al2O3)}(11.87x_{(MnO)} - 10.45x_{(CaO)} + 13.79x_{(MgO)})] \qquad Eqn.\,1$$

where x_i is the cation fraction in the oxide i which can be calculated as follows

$$x_i = \frac{\nu i n i}{\sum \nu i n i} \qquad Eqn.\ 2$$

in which νi and ni are the number of cations in a molecule of the oxide i and the number of moles of the oxide in 100g of the slag respectively.

Effect of slag composition on activity coefficient of silica in slag

For finding the effect of slag composition on the activity coefficient of silica, as determined by Equations 1 and 2, lnγ(SiO2) was correlated with slag beasicity, defined in different forms for all samples (67samples), over the whole temperature range from 1340 to 1412oC. The results may be summarized by the following equations:

$\ln\gamma_{(SiO_2)}(B_1)=-0.9469B_1-0.5818$, r=0.5484 $Eqn.\,3$

$B_1 = (CaO)/(SiO_2)$

$\ln\gamma_{(SiO_2)}(B_2)=-1.9923B_2+0.2157$, r=0.8401 $Eqn.\ 5$

$B_2 = (CaO + MgO)/(SiO_2 + Al_2O_3)$

$\ln\gamma_{(SiO_2)}(B_3)=-2.1855B_3+0.5755$,

r=0.8675 7 $Eqn.\,7$ $B_3 = (CaO + MgO + MnO)/(SiO_2 + Al_2O_3)$ $Eqn.\,8$

$\ln\gamma_{(SiO_2)}(B_4)= -2.1768B_4+0.688$,

r=0.8765 $Eqn.\,9$

$B_4 = (CaO + MgO + MnO + BaO)/(SiO_2 + Al_2O_3)$ $Eqn.\,10$

$Ln\gamma_{(SiO_2)}(B_5)=-2.1949B_5+0.7096$,

r=.9139 $Eqn.\ 11$

$B_5 = (CaO + 1.4MgO + 0.79MnO + 0.37BaO)/(SiO_2 + Al_2O_3)$ $Eqn.12$

Among all empirical equations, formula showing correlation between lnγ $_{(SiO2)}$ and B_5 which contains the CaO and its equivalents of the basic oxides MgO,MnO and BaO has the most suitable value of correlation coefficient(r). It is, therefore, obvious that the activity coefficient of silica in the blast furnace slag

Table 1 Hot metal temperature, in OC and chemical analysis of slag and hot metal, in wt.%.

emical	Analysis	Of	Slag					chemical	Analysis	Of hot me
	FeO	SiO_2	CaO	Al_2O_3	MnO	S	BaO	Mn	S	Si
1393	0.39	35.75	35.28	11	3.6	1.23	2.8	1.85	0.058	0.49
1395	0.26	35.6	35.47	12.36	3.67	1.16	2.9	1.78	0.058	0.44
1398	0.39	36.88	35.24	11	3.9	1.2	2.54	2	0.04	0.57
1403	0.39	35.67	36.33	10.52	3.66	1.25	2.5	2.3	0.021	0.57
1382	0.39	35.58	35.32	11.08	4.16	1.19	2.66	2.04	0.029	0.33
1388	0.52	36.42	34.56	11.4	4.26	1.18	2.9	1.65	0.058	0.37
1382	0.52	36.5	33.54	12	4.38	1.2	3.15	1.65	0.067	0.4
1389	0.52	34.93	34.27	12.1	4.13	1.13	2.96	1.94	0.048	0.34
1397	0.39	35.78	33.61	11.02	4.8	1.27	2.8	2.36	0.037	0.42
1387	0.52	36.07	33.54	11.62	4.6	1.27	2.9	2.16	0.042	0.54
1395	0.39	36.43	34.58	11.22	4.29	1.28	3	2.14	0.043	0.56
1388	0.39	36.88	34.35	10.65	3.5	1.15	2.9	1.96	0.051	0.47
1340	0.26	37.7	31	12.2	3.87	1.1	3.02	1.47	0.084	0.48
1358	0.26	35.96	33.45	12.6	3.5	1.26	3.5	2.02	0.048	0.42
1412	0.26	37.05	36.07	11	3.12	1.28	2.5	2.1	0.034	0.41
1392	0.26	36.38	34.95	11.5	4.13	1.29	2.9	2.02	0.033	0.51
1394	0.26	37.16	35.05	12.3	3.67	1.2	2.66	2.12	0.042	0.57
1395	0.26	35.7	35.39	12.48	3.72	1.22	2.7	1.99	0.057	0.49
1403	0.26	34.98	39.42	10.3	3.56	1.45	2.9	2.43	0.021	0.67
1407	0.26	35.96	36.97	11.8	3.9	1.4	2.82	2.08	0.038	0.49
1400	0.26	36.67	35.86	11.2	4.39	1.38	2.9	2.1	0.043	0.43
1376	0.39	36.99	35.55	10.77	5.68	1.29	2.63	1.67	0.077	0.42
1394	0.52	39.55	33.93	12.4	4	1.23	2.9	1.74	0.072	0.55
1401	0.26	36.23	38.06	11.5	3.61	1.34	2.66	2.33	0.028	0.68
1400	0.39	37.3	34.72	11.34	3.96	1.25	3.02	1.99	0.053	0.56
1401	0.52	36.3	35.22	12.1	3.9	1.33	2.89	1.8	0.069	0.41
1387	0.77	35.52	36.32	9.4	5.5	1.36	2.56	1.72	0.06	0.36
1380	0.77	35.73	36.45	10.2	5.16	1.35	2.61	1.91	0.049	0.46
1378	0.77	37.83	32.23	11.2	5.8	1.37	3.1	1.34	0.099	0.44
1398	0.52	37.73	33.65	11.4	4.2	1.33	3.8	1.59	0.088	0.48
1400	0.52	37.4	34.92	11.2	3.6	1.29	3.3	2.14	0.042	0.58
1407	0.52	36.92	33.92	12.11	4.33	1.34	2.48	1.96	0.05	0.5
1401	0.52	37.81	32.82	13.1	4.8	1.15	2.8	1.64	0.076	0.45
1380	1.42	37.73	31.22	10.7	6.39	1.06	2.7	1.34	0.098	0.4
1411	0.52	37.67	31.59	12.39	4.54	1.21	2.58	1.82	0.052	0.61
1404	0.65	37.1	32.55	10.88	4.84	1.29	2.75	1.75	0.069	0.54
1409	0.39	36.91	35.09	10.5	4.2	1.27	3.1	1.9	0.054	0.55
1407	0.39	37.27	31.23	13	5.8	1.24	3.1	1.61	0.078	0.51
1385	0.77	35.96	33.79	12.54	5.41	1.25	2.17	1.43	0.077	0.26
1381	1.03	36.98	31.41	12.7	6.12	1.08	1.91	1.19	0.122	0.32
1400	0.52	36.8	32.52	11.9	4.8	1.17	2.81	1.78	0.066	0.54
1411	0.52	34.98	35.3	12.8	4.52	1.31	2.58	2.15	0.028	0.69
1403	0.77	35.55	34.5	12.5	4.13	1.33	2.84	1.97	0.044	0.49
1385	0.65	34.91	36.54	11.84	4.2	1.31	1.89	1.95	0.038	0.39
1400	0.52	33	38.8	13	3.04	1.45	2.28	2.04	0.038	0.49
1387	0.39	35.81	35.9	12.8	3.35	1.34	2.34	2.14	0.024	0.67
1396	0.39	36.76	31.99	12.6	3.6	1.22	3.45	2.07	0.055	0.5
1401	0.39	35.84	33.7	12.9	3.87	1.26	3.32	2.05	0.054	0.6
1399	0.39	35.61	32.84	12.84	4.83	1.15	2.44	1.98	0.055	0.45
1396	0.39	34.74	34.92	11.9	3.2	1.24	2.61	2.02	0.035	0.39
1378	0.39	35.97	33.51	11.05	5.85	1.14	2.38	1.39	0.074	0.22
1398	0.39	36.38	33.41	13	3.6	1.19	2.6	1.79	0.07	0.58
1402	0.65	32.78	37.58	13.3	2.97	1.31	1.91	2.25	0.023	0.62
1396	0.77	33.76	37.06	12.49	4.67	1.39	1.7	2.18	0.03	0.44
1411	0.52	33.65	36.47	13.3	3.55	1.31	1.8	2.53	0.037	0.56
1401	0.65	36.53	32.27	13.36	4.85	1.15	1.61	2.2	0.053	0.45
1363	0.77	39	29.12	11.48	6.45	1.11	2.27	1.68	0.104	0.5
1387	0.77	38.86	29.13	13.8	4.77	1.12	2.3	1.59	0.122	0.6
1381	0.52	37.41	29.7	13.5	5.81	1.13	2.63	1.62	0.088	0.67
1397	0.52	37.81	30.82	11	4.6	1.22	3.2	1.7	0.102	0.58
1404	0.39	37.03	32.3	11.1	4.3	1.18	3.3	1.99	0.052	0.62
1404	0.26	37.21	32.38	10.9	4.3	1.23	3.2	1.97	0.063	0.66
1391	0.77	38.06	31.81	12.57	4.26	1.21	1.92	1.74	0.082	0.69
1395	0.39	38.7	32	11.38	4.61	1.15	2.24	1.63	0.089	0.53
1382	0.52	37.9	33.08	11.04	4.6	1.17	2.09	1.78	0.079	0.51
1390	0.39	38.91	32.11	11.18	4.6	1.13	2.29	1.52	0.093	0.41
1410	0.39	37.06	30.68	11.2	3.55	1.3	2.24	1.9	0.067	0.63

satisfactorily correlates with the slag basicity comprising CaO and all lime equivalents of the basic oxides in the slag under the conditions of BF operation at EISCO as presented in Figure 1. Accordingly, correlation of silica activity with the slag basicity should make use of this finding. This will be considered in all subsequent calculations involving

$a_{(SiO2)}$ such as silicate capacity and silicon distribution between slag and hot metal, as will be discussed later.

Activity of silica in slag

The activity of silica in the slag $a_{(SiO2)}$ is calculated by multiplying the activity coefficient by the cation fraction $x_{(SiO2)}$ as follows:

$$a_{SiO2} = \gamma_{SiO2*x_{SiO_2}} \qquad Eqn. 13$$

Combined effects of slag basicity and temperature on silica activity

The combined effects of both basicity and temperature on the activity of silica in the slag can be estimated by plotting the logarithm of a_{SiO2} as calculated by Equations 1, 2 and 13 against B_5 which accounts for CaO and its equivalents of basic oxides in the slag at constant average temperatures as shown in Figure 2. The straight lines represent the variation of lna_{SiO2} with B_5 at the constant temperatures 1381, 1394 and 1410 ^oC. They are more or less parallel and have an average slope equal to -2.8197. The three lines can be represented by the general equation

$$lna_{SiO2}(B,T) = -2.8197B5 + b \qquad Eqn. 14$$

The value of the slope depends on the basicity whereas the values acquired by intercept, b, of the three lines with the ordinate are dependent on the temperature as follows.

b=0.3514 at t=1381^{o}C (15)

b=0.3395 at t=1394^{o}C (16)

b=0.2308 at t=1410^{o}C (17)

Figure 3 depicts the variation of the intercept, b, with the reciprocal of the corresponding absolute temperature. The straight line can be described by the equation

$$b = \frac{10802}{T} - 6.1693 \ , \ r = 0.8478 \qquad Eqn. \quad 18$$

Substituting for b from Equation 18 in Equation 14 results in

$$lna_{SiO2}(B,T) = -2.8197B5 + 10802/T - 6.1693 \qquad Eqn. \ 19$$

This equation shows that the activity of silica in the slag decreases with increasing basicity and temperature. Activity of silicon in hot metal

The activity of silicon in hot metal, $\boldsymbol{aSi}$ is calculated in the present work by using the dilute solution model as follows

$$\boldsymbol{aSi = fSi[Si]} \qquad Eqn. 20$$

where $f[Si]$ is the activity coefficient of silicon in the metal and[Si] is its concentration in weight percent. The activity coefficient can be estimated by

$$\boldsymbol{logfSi = e^{Si}_{Si[Si]+\sum e^i_{Si}[i]}} \qquad Eqn. 21$$

in which $\boldsymbol{e^{Si}_{Si}}$ is interaction parameter of the element i dissolved in the metal and[i] is the concentration, in wt%. The interaction parameters are given in Table 2 [18].

Table 2 Interaction parameters, e_Si^i [18].

e^{Si}_{Si}	e^{C}_{Si}	e^{Mn}_{Si}	e^{S}_{Si}	e^{P}_{Si}
34.5/T+0.089	38/T-0.023	0.002	0.056	0.11

The results are summarized in Figure. 4 which shows the variation of the activity with the concentration of silicon in the metal. The straight line can be described by the regression equation

$$\boldsymbol{aSi} = 1.324[Si], \quad r = 0.9929 \qquad Eqn. 22$$

The high value of the correlation coefficient indicates strong linear relationship between activity and concentration of silicon in the metal. The ranges of silicon concentration and hot metal temperature in which this equation was obtained are

0.22 ≤ [Si] ≤ 0.6 9 and 1340 ≤ t ≤ 1412

where t is the hot metal temperature, inoC.

By comparing Equation 20 with Eq 22 the following value is obtained for the activity coefficient of silicon in the metal

$$\boldsymbol{fSi} = 1.324 \qquad Eqn. 23$$

The relatively high value of the activity coefficient may be explained by the relatively high concentration of silicon in the metal.

Silicate capacity of slag

In the present work the estimation of the silicate capacity, CSi, is based on the oxidation of silicon in iron according to the reaction

[Si] + O2 = (SiO2) $Eqn. 24$

$$CSi = \frac{(Si)}{aSiPO2} \qquad Eqn. 25$$

where (Si) is the silicon equivalent of SiO2 in the slag, in wt %. It is equal to 0.4674 multiplied by the mass percentage of SiO2 in the slag. The partial pressure of oxygen, PO2, can be calculated by using the equilibrium constant, KSi, of the above mentioned oxidation reaction of silicon as follows

$$pO2 = \frac{\boldsymbol{aSi02}}{\boldsymbol{aSi}KSi} \qquad Eqn. 26$$

where

$$lnKSi = \frac{96356}{T} - 24.868 \quad Eqn. 27$$

From Equations 25 and 26 it follows that

$$CSi = \frac{(Si)KSi}{\boldsymbol{aSiO2}} \qquad Eqn. 28$$

The activity of silica can be calculated with the help of Equations. 1, 2 and 13.

Effect of temperature on silicate capacity

The variation of silicate capacity of the slag, as calculated by using Equations from 25 to 28 with temperature is illustrated in Figure 5. The straight line correlates lnCSi with the inverse of absolute temperature over the whole range of basicity for all samples used in this research. It satisfies the empirical formula

$$lnCSi = \frac{98908}{T} - 21.082, \quad r = 0.9486 \qquad Eqn. 29$$

The high correlation coefficient indicates that the silicate capacity is mainly dependent on temperature. The ranges of temperature and basicity in which Equation 29 has been obtained are 1340 oC ≤ t ≤ 1412 oC and 0 .9034 ≤ B5 ≤1.0359.

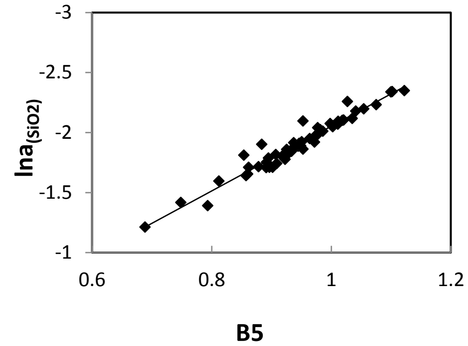

Figure 1 Variation of the activity coefficient of SiO2 with the slag basicity B5 over the temperature range 1412 ≥ t ≤ 1340oC.

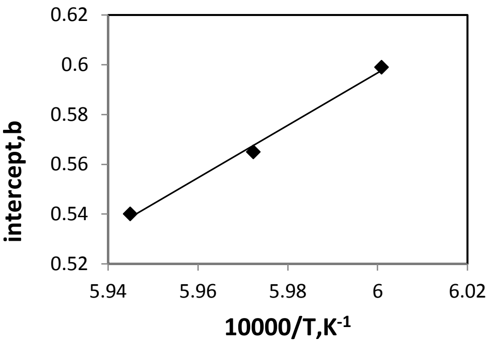

Figure 2 Variation of the intercept of the straight lines, b, in Fig.2 with the inverse of absolute temperature

Combined effects of basicity and temperature on silicate capacity

In order to assess the combined effects of both basicity and temperature on silicate capacity of slag, lnC_{Si} is plotted against the reciprocal of absolute temperature at constant basicity as given in Figure 6. The constant basicity is the average value of slag basicities selected in a very narrow range at a given temperature. The straight lines in Figure 6 illustrate the change of silicate capacity of the slag with the inverse absolute temperature at constant B_5. The four lines are roughly parallel and have an average slope and correlation coefficient equal to 101320 and 0.9841, respectively. They can be represented by the general formula

$$lnCSi(T,B) = \frac{101320}{T} + d \quad Eqn.30$$

The intercept with the ordinate, d, has the following values at the given basicities:

$$d = -22.166 \ at \ B_5 \ 1.0850 \quad Eqn.31$$
$$d = -22.375 \ at \ B_5 \ 1.00\,37 \quad Eqn.32$$
$$d = -22.363 \ at \ B_5 \ 0.9449 \quad Eqn.33$$
$$d = -23.223 \ at \ B_5 \ 0.8976 \quad Eqn.34$$

The correlation of the values of d, in Equations 31 to 34 with the corresponding values of the basicity B_5 yields:

$$d = 4.7581\ B_5 - 27.208\ , \quad \mathrm{r} = 0.8164 \quad Eqn.35$$

From Equations 30 and 35 the variation of lnC_{Si} with both temperature and basicity can be expressed by

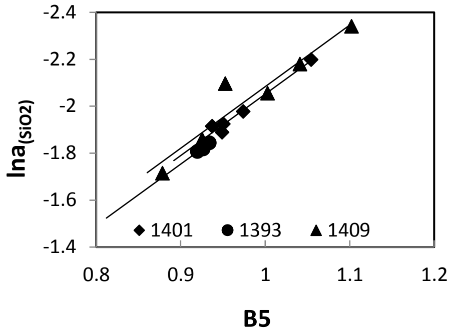

Figure 3 Variation of the activity of SiO2 with the slag basicity at the temperatures 1381, 1394, 1410oC in the basicity range 0.980688 ≥ B5 ≤0.998807.

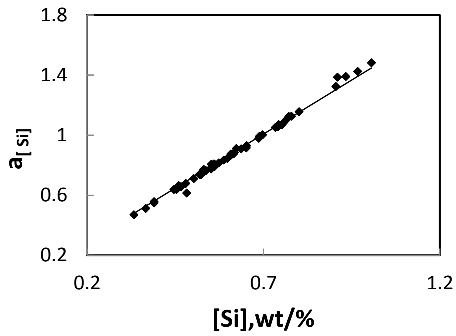

Figure 4 Variation of the activity with the concentration of silicon in hot metal.

$$lnCSi(T,B) = \frac{101320}{T} + 4.7581B5 - 27.208 \quad Eqn.36$$

The corresponding expressions for B_1 to B_4 are:

$$lnCSi(T,B) = \frac{101320}{T} + 3.5656B_1 - -25.755 \quad Eqn.37$$

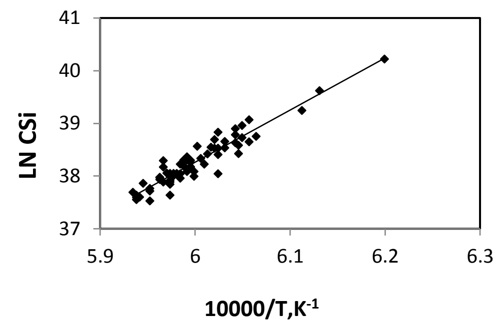

Figure 5 Variation of silicate capacity of slag with the temperature in the ranges of temperature 1340 oC ≤ t ≤ 1412 oC and 0 .9034 ≤ B5 ≤1.0359.

$$lnCSi(T,B) = \frac{101320}{T} + 4.6349B2 - 26.377 \quad Eqn.38$$

$$lnCSi(T,B) = \frac{101320}{T} + 5.0028B_3 - 27.161 \quad Eqn.39$$

$$lnCSi(T,B) = \frac{101320}{T} + 4.8016B4 - 27.201 \quad Eqn.40$$

Equations 36 to 40 show that the silicate capacity of the slag decreases with decreasing basicity and increasing temperature. This may be explained by the lower ability of the slag to form silicates as the basicity decreases and the enhancement of the endothermic reactions of silica reduction at high temperatures. This trend agrees with the results of investigation obtained elsewhere[20]. The temperature coefficient in Equations 36 to 40 does not differ significantly from the temperature coefficient in Equation29, indicating the minor effect of basicity on C_{Si} compared with the influence of temperature.

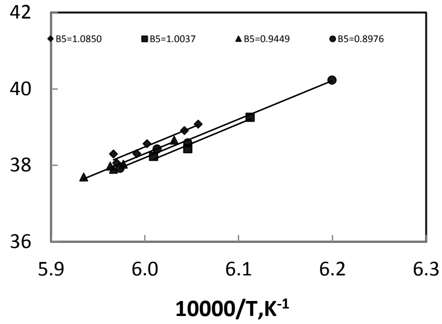

Figure 6 Variation of silicate capacity of slag with the temperature at constant basicity B5= 0.8976, 0.9449, 1.0037 and 1.0850

Silicon distributions between slag and metal

The distribution ratio of silicon between blast furnace slag and hot metal, η_{Si}, may be expressed as follows

$$\eta Si = \frac{(Si)}{[Si]} \qquad Eqn.41$$

From this equation and Eq. (28), it follows that

$$\eta Si = \frac{CSia(SiO2)}{[Si]KSi} \quad Eqn.42$$

The silicate capacity in this equation can be calculated by using Equations 36 to 40. The activity of silica may be estimated with the help of Equations. 1, 2 and 13. The equilibrium constant K_{Si} is given by Equation 27.

Combined effects of basicity and temperature on silicon distribution

Substituting for C_{Si}(B,T), $a(SiO2)$ $_{(B,T)}$,K_{Si} and [Si] from the hot metal analysis, the following expressions are obtained for the silicon distribution ratio as a function of basicity and temperature :

$$\eta Si(B,T) = \exp(\frac{42229}{T} + 2.0933B_1 - 24.352)/[Si] \quad Eqn.43$$

$$\eta Si(B,T) = \exp(\frac{22264}{T} + 2.0669B_2 - 12.200)/[Si] \quad Eqn.44$$

$$\eta Si(B,T) = \exp(\frac{58395}{T} + 1.8673B3 - 33.884)/[Si] \quad Eqn.45$$

$$\eta Si(B,T) = \exp(\frac{336}{T} + 1.9074B4 - 0.8161)/[Si] \quad Eqn.46 \qquad (46)$$

$$\eta Si(B,T) = \exp(\frac{15768}{T} + 1.9384B5 - 8.5093)/[Si] \quad Eqn.47$$

The distribution ratios, $\eta Si(B,T)$, were calculated according to the above equations for the above mentioned 67 slag and the corresponding hot metal samples .

The calculated values $\eta Si(B,T)$are plotted versus the corresponding data obtained by chemical analysis $\eta Si(obs)$. As an example $\eta Si(B5,T)$ is plotted against $\eta Si(obs)$ in Figure 7. The straight line satisfies the formula.

$$\eta Si(B5,T) = 1.0569\eta Si(obs), \quad r=0.8458 \qquad Eqn.48$$

The factor of $\eta_{Si(Obs)}$ differs from unity only by 5.4% and the correlation coefficient is relatively high indicating satisfactory agreement between calculated and observed values of silicon distribution ratio.

The sensitivity of silicon distribution to temperature and basicity can be illustrated by using Equation 47 and making the following assumptions

1) The basicity B_5 is kept constant at 1.0 and the temperature is raised from 1350 to 1400°c and [Si] is kept at 0.5 %. In this case η_{Si} changes from 46.41 to 34.72, i.e. η_{Si} drops by 25.19%(0.5%/°C)

2) If the temperature is kept constant at 1400 °c and B_5 is changed from 1.0 to 1.1 and [Si] is kept at 0.5 % η_{Si} changes from 34.72 to 42.14, i.e., it increases by 21.37% relative to η_{Si} at B_5= 1.0. This stresses the strong effect of basicity and temperature on η_{Si} in blast furnace.

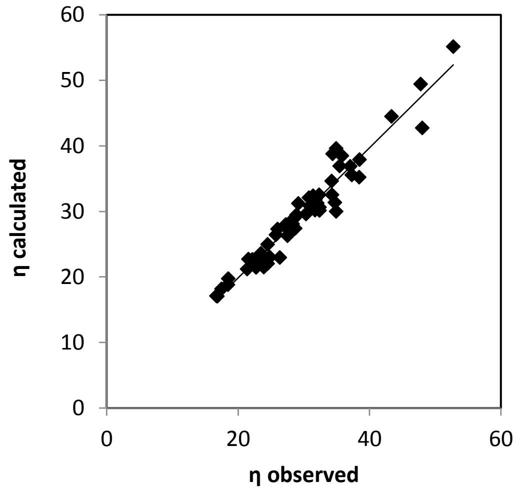

Figure 7 Relation between the calculated values of the slag –metal distribution ηSi(B5,T) ratios and the corresponding data obtained from chemical analyses, ηSi(obs).

Conclusions

Daily average data on slag and the corresponding hot metal analyses of BF No.III of the Egyptian Iron and Steel Company (EISCO) were used to investigate the effects of slag basicity and hot metal temperature on the activity coefficient and activity of silica in the slag . The temperature of hot metal was measured during metal tapping. The furnace has a useful volume of 1033m^3. The charge consisted of 100% self- fluxing sinter. The influence of basicity and temperature on the silicate capacity of the slag and silicon distribution between slag and hot metal was also investigated. The variation of silicon activity with the concentration in hot metal was tested. Based on the investigation results, the following conclusions can be made:

- The activity coefficient of silica correlates linearly with the basicity.
- The best correlation is obtained when CaO and its equivalents of basic oxides are included in the basicity definition.

- The activity of silicon correlates linearly with the concentration over the whole concentration range (0.22-0.69wt %) and the activity coefficient of silicon in the metal is 1.324.
- The influence of temperature on the silicate capacity and silicon distribution between slag and hot metal is very large compared with the small effect of basicity.
- The silicon distribution between slag and metal calculated by using the silicate capacity at different temperatures and basicities agrees reasonably with the corresponding values obtained from slag and metal analyses.

Acknowledgments

The author wishes to thank the Egyptian Iron and Steel Company (EISCO) for providing the BF data.

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List of symbols

$a_{(SiO2)}$: silica activity in slag
aSi : Silicon activity in hot metal
B:basisty
b: intercept
d: intercept
C_{Si} :silicate capacity
f[Si] : activity coefficient of silicon in metal
e_{Si}^{i}: Interaction parameters
K_{Si} :equilibrium constant
P_{O2}: oxygen partial pressure
T: Absolute temperature
t : hot metal temperature
η_{Si}: silicon distribution ratio